*TM 5-230

TECHNICAL MANUAL No. 5-230

WAR DEPARTMENT, WASHINGTON, *November 12, 1940.*

TOPOGRAPHIC DRAFTING

Prepared under direction of the Chief of Engineers

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SECTION I

GENERAL

1. Purpose and scope.—*a. Purpose.*—The purpose of this manual is to provide a single text on the technique and methods of training the military personnel employed on topographic drafting. The material is presented in the order best suited for a normal course of instruction, starting with basic subjects and gradually taking up the more complicated operations which an experienced draftsman or photogrammetrist is expected to perform.

b. Scope.—The text embraces the entire range of subjects relating to topographical drafting and necessarily includes basic instructions in the use and care of drafting equipment, the fundamentals of drafting, and the use of aerial photographs.

2. Courses of instruction.—Sections II and III give the description and proper use of all instruments and materials used in the drafting room. Section IV contains directions for laying out and making drawings in pencil and ink, with indications of the problems which a military draftsman may encounter, and shows, so far as practicable, complete examples of the described work. Upon the completion of a course covering the subjects in sections III to VIII, inclusive, the student should be able to meet the drafting requirements of smaller combat units. For larger units and specialized organizations, the student should be required to complete a course covering substantially all the subjects of the entire text before he may be considered capable of assuming the more exacting duties of a draftsman or photogrammetrist in such organizations. For an outline of a complete instruction course see section XXIV.

SECTION II

DESCRIPTION OF EQUIPMENT

3. Drawing board.—*a.* The best drawing board is made of strips of soft white pine glued together with two or more cleats across the back and fastened in such a way as to allow the wood in the board to expand or contract. The surface of the board should be perfectly true, and one end and one side of the board must be perfectly straight and at right angles with each other.

b. The board should be supported by either a tripod or frame rigid enough to prevent vibration. It is convenient to be able to slant the board but not at all necessary for good work. A drawer in the support frame is desirable. A stool should be used which is high enough to enable the draftsman to cast his eye over all parts of the drawing.

4. Light.—The drawing table should be so placed as to obtain a soft, uniformly diffused light over the entire board. It should not be set directly in front of a window, since the glare caused by reflection is a source of annoyance and eye strain. The most advantageous direction of light is from the upper left-hand corner of the board. Work should be so conducted that the T-square, triangles, and hands will not cast a shadow on the lines which are being drawn.

5. T-square.—The ordinary T-square consists of two parts, the head and the blade, fastened together at right angles. It is used for drawing horizontal lines *only*. (See fig. 1.) Adjustable heads are provided on some T-squares to facilitate the drawing of parallel lines at an angle to the horizontal. (See fig. 2.)

6. Triangles.—Standard triangles used in drafting are the 45° triangle and the 30°–60° triangle (fig. 3 ① and ②). In addition, lettering triangles (fig. 3 ③) are useful for line spacing. When the sharpened point of a pencil is inserted consecutively in the holes of a vertical series, and the triangle is slid along a T-square, parallel lines are drawn at appropriate intervals. Transparent celluloid triangles are lighter than wooden or metal triangles and permit the work to be seen through them.

7. Scales.—*a. Definition.*—In preparing a scale drawing, all dimensions of the represented object are multiplied by a fixed factor known as the scale. In the usual case, when the drawing is smaller than the object, this factor is a proper fraction. To facilitate the application, special measuring rulers with proportional markings have been devised, and these also are called scales.

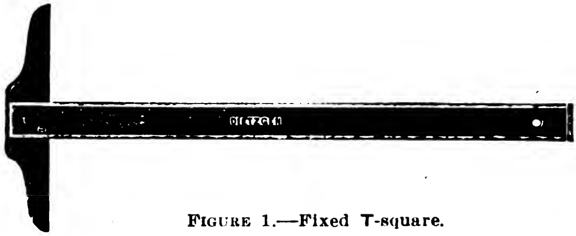


FIGURE 1.—Fixed T-square.

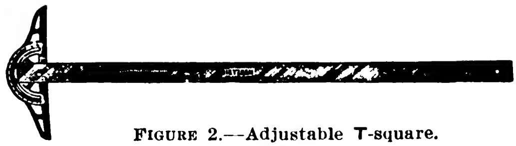
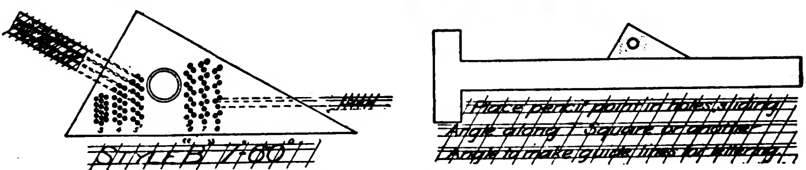


FIGURE 2.—Adjustable T-square.

① 30°-60° triangle.

② 45° triangle.



③ Lettering triangles.

FIGURE 3.—Triangles.

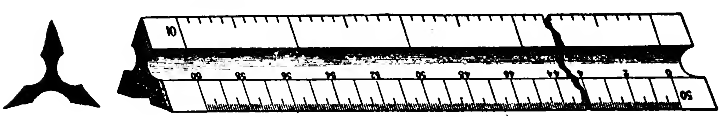


FIGURE 4.—Engineer scale.

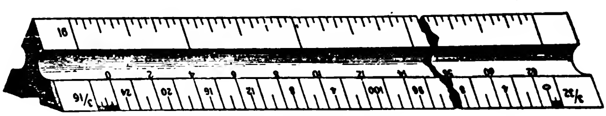


FIGURE 5.—Architect scale.

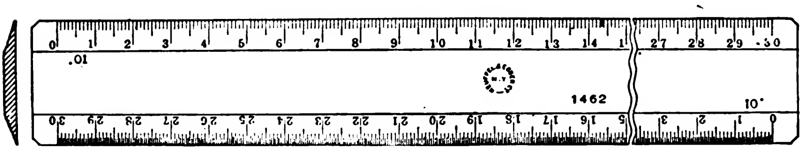


FIGURE 6.—Metric scale.

b. Engineer and architect scales.—(1) The two types of scales most used in drafting are known as the engineer scale (fig. 4) and the architect scale (fig. 5). On the former, inches are subdivided into 10, 20, 30, 40, 50, or 60 parts, with longer division lines for each group of 5 and 10 small units; on the latter, the subdivisions usually follow the series $\frac{1}{16}''$, $\frac{3}{32}''$, $\frac{1}{8}''$, $\frac{1}{4}''$, $\frac{3}{8}''$, $\frac{1}{2}''$, $\frac{3}{4}''$, 1″, $1\frac{1}{2}''$, 3″. The scales most used are 1 foot long and have a triangular cross section grooved for lightness and convenience of handling.

(2) In the middle of each edge is the number which indicates how many of the smallest divisions there are to the inch on this edge. These scales are adapted to maps or plans on scales of—

$1''=10'$, $1''=100'$, $1''=1{,}000'$, etc., for the 10 scale;
$1''=20'$, $1''=200'$, $1''=2{,}000'$, etc., for the 20 scale;

and so on. The architect triangular scale usually provides 11 distinct scales, 2 on each of 5 edges, in pairs as follows: $\frac{3}{32}''$ and $\frac{3}{16}''$, $\frac{1}{8}''$ and $\frac{1}{4}''$, $\frac{3}{8}''$ and $\frac{3}{4}''$, $\frac{1}{2}''$ and 1″, $1\frac{1}{2}''$ and 3″, and 1 on one edge divided into $\frac{1}{16}''$. In the case of each pair, one scale reads from the left end while the other reads from the right end. These scales are particularly adapted for use when dimensions are expressed in feet and inches; feet are read on one side of the zero of the scale and inches on the other side. The engineer scale is used principally on topographical drawings, the architect scale on mechanical drawings.

c. Metric scales.—For certain work metric scales subdivided to suit particular conditions are available (fig. 6). Comparing its subdivisions (centimeters and millimeters) with the subdivisions of the

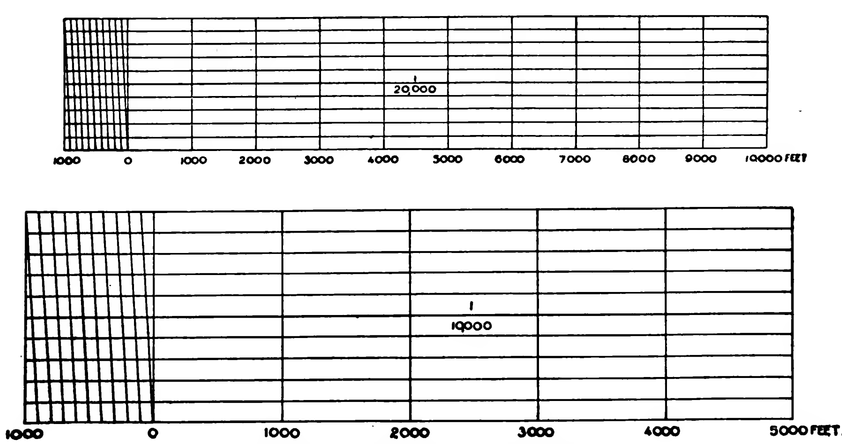


FIGURE 7.—Standard plotting scales.

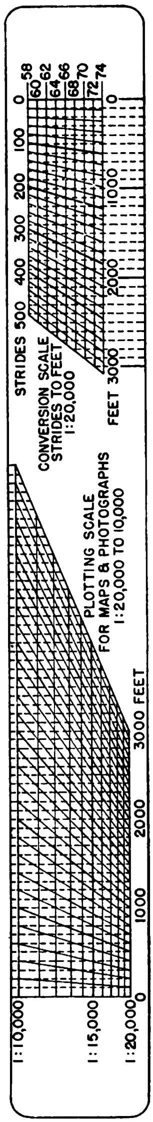


FIGURE 8.—Polygraph scale.

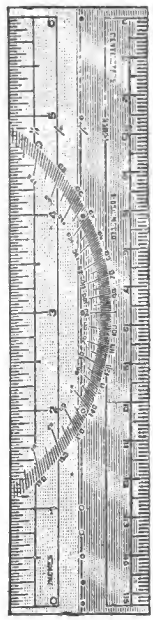


FIGURE 9.—6-inch transparent scale.

engineer or architect scale, it will be seen that 25 millimeters (or 2.5 centimeters) are nearly equal to 1 inch.

d. Plotting scales.—Figure 7 shows two plotting scales, full size, the upper one for use on 1:20,000 maps or drawings and the lower one for use on 1:10,000 maps. Subdivisions of 1,000 units are marked on the bottom of each scale and may be measured at the left or subgraduated end to include units of 100 and units of 10.

e. Photograph scales.—Figure 8 represents a so-called polygraph scale, which graphically converts and permits the plotting or measuring of distances on drawings or photographs to any scale between 1:10,000 and 1:20,000. It is especially useful for working on aerial photographs when a standard scale is not usable. For further explanation of this scale see paragraph 59, FM 21-35.

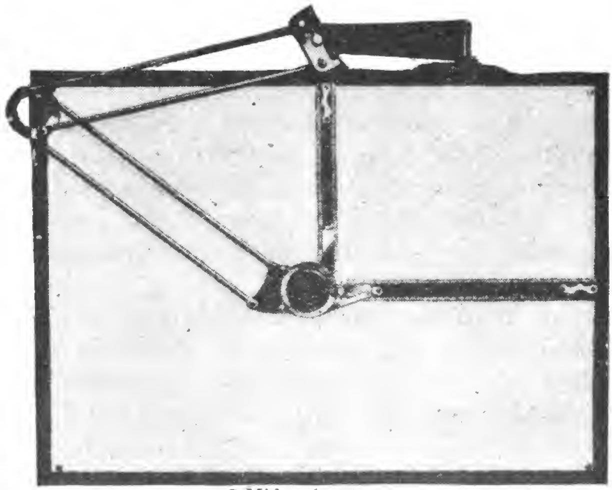
f. Miscellaneous scales.—For drawing projections, etc., a steel plotting scale, 50 inches long, is sometimes suitable. Transparent scales with various graduations and combinations for plotting may also be used. Figure 9 shows such a scale, full size, made of two thicknesses pressed together, with graduations impressed on the inside to prevent wear and ink stain.

8. Universal drafting machine.—This machine (fig. 10) eliminates the manipulation and handling of T-squares, triangles, and scales, and facilitates drafting operations. It saves from one-fourth to one-half the time ordinarily required in making drawings. The construction of the machine is such that it gives to its working end a parallel motion about the drawing. There are two general types of universal drafting machines, the midanchor type (fig. 10 ①) and the corner anchor type (fig. 10 ②), the first-named type being preferred as it requires no clearance at the end of the drawing board. Various interchangeable scales permit an unlimited range of work. This machine constitutes the drawing attachment of the stereo-comparagraph described in paragraph 82*e*.

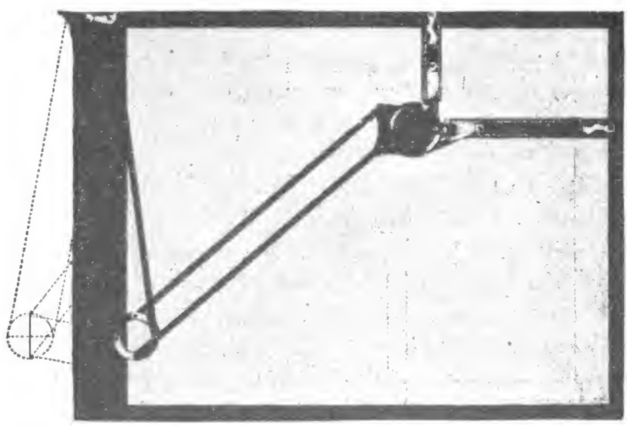
9. Drawing instruments.—*a. General.*—The drawing instruments most commonly used are described in this paragraph. Drawing instruments and equipment must be well cared for, properly cleaned each time after using, and the points prevented from coming into contact with hard substances which will tend to injure them.

b. Compass and divider.—(1) The compass (fig. 11) is an instrument used in describing circles or arcs. It has two legs hinged at the top by a friction joint for establishing the radius. The joint should not be oiled because the pivot has just enough friction to hold the legs at a setting while drawing arcs. One leg ends in a needle

point which is pricked lightly into the point which is to be the center of the arc. The other leg is provided with a socket and set screw to receive either a pen or pencil attachment. Both legs are provided with knuckle joints so that the points can be kept vertical as the radius is increased. The lead should be sharpened to a fine wedge point with its long dimension at right angles to the line joining the points. The lead should be so adjusted in the pencil attachment that the needle point will project slightly beyond it when the two legs are pressed together.



① Midanchor type.



② Corner anchor type.

FIGURE 10.—Universal drafting machine.

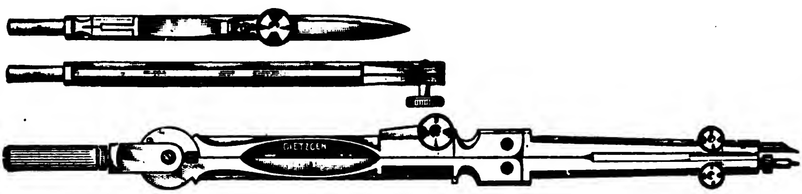
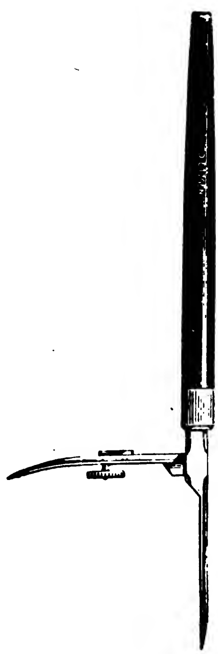


FIGURE 11.—Compass.

FIGURE 12.—Divider.

(2) The divider (fig. 12) is an instrument like the compass except that both legs are provided with needle points. It is used in laying off series of equal spaces and in transferring distances. In pricking off these points the holes should be made very small. The position of a small prick point may be marked for easy identification by drawing a small free-hand circle around it.

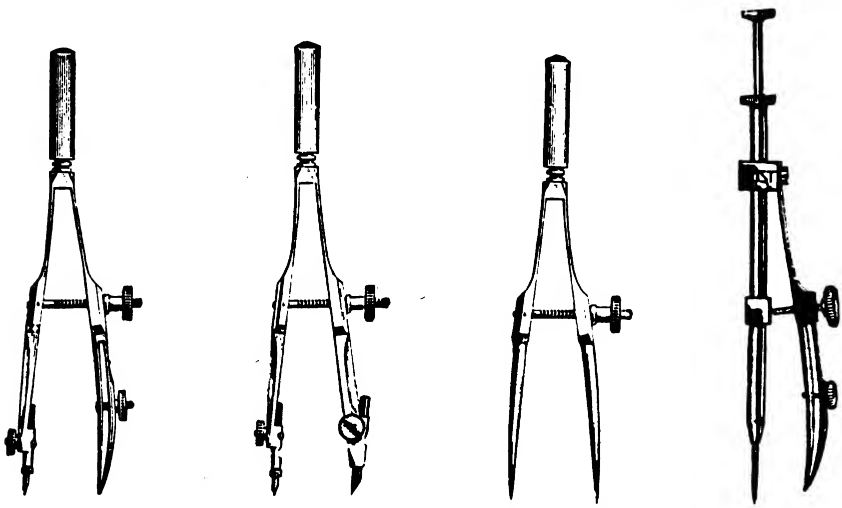
c. Ruling pens.—The ruling or right line pen consists of two steel blades, a set screw, and a handle. The blades are of equal length,



① Ordinary type. ② Hinged blade type.

FIGURE 13.—Ruling pens.

pointed and sharpened at their lower ends (fig. 13①). The points can be adjusted by means of the screw to draw a line of any desired width. The common types have a spring upper blade with enough spring to allow opening for cleaning. The more expensive types have a hinged upper blade (fig. 13②) actuated by a spring, similar to a pocket knife, which either holds it open at 90° or presses it firmly against the fixed blade. The ruling pen is the most frequently used of



① Bow pen. ② Bow compass. ③ Bow divider. ④ Drop pen.

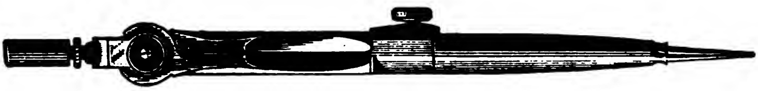
FIGURE 14.—Bow spring instruments and drop pen.

all instruments and therefore the most important. It is used to draw all straight and irregularly curved lines and is always guided by the edge of a T-square, triangle, or curve. Fine lines are drawn with the smaller ruling pens, heavier lines with the larger pens. They are usually filled with a quill attached to the cork of each bottle of ink, the ink not to be more than 1/4 inch deep between the nibs of the pen. The ruling pen must be frequently cleaned during use and must never be put away without being thoroughly cleaned and dried.

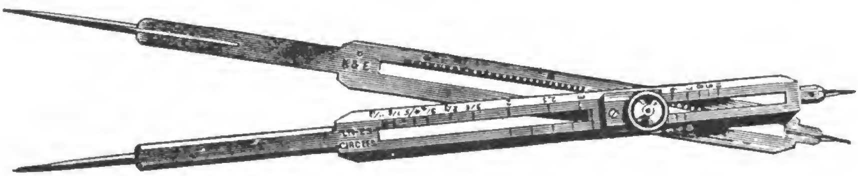
d. Bow spring instruments and drop pen.—Bow spring instruments, that is the bow pen, bow compass, and bow divider, are used for circles or arcs between 1/4 and 1 inch in diameter. The drop pen is used to ink smaller circles about 1/30 to 1/8 inch in radius. (See fig. 14.)

e. Tracing point.—The tracing point (fig. 15①) is of occasional value, especially for pricking points from one drawing onto another. Many ruling pens have a tracing point on the handle.

① Tracing point.



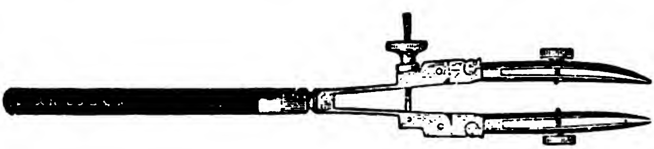
② Hairspring dividers.



③Proportional dividers.

④ Contour pen.

⑤ Swivel road pen.



⑥ Railroad pen.

FIGURE 15.—Drawing instruments.

f. Hairspring dividers.—Hairspring dividers (fig. 15 ②) are distinguished from plain dividers by having a screw adjustment on one leg to facilitate accurate settings.

g. Proportional dividers.—Proportional dividers (fig. 15 ③) are used for enlarging or reducing according to any proportion. On one edge are divisions for setting to linear proportions, while on the other are divisions for setting to circular proportions, the latter for dividing a circle (the diameter of which is measured by the large end of the dividers) into the desired number of equal parts.

h. Swivel pens.—The contour pen (fig. 15 ④) also called a curve pen, is used for inking single, irregular, curved lines, especially contours. It is indispensable to a topographical draftsman. The swivel road pen (fig. 15 ⑤) is of great value when inking irregular curved roads represented by a double parallel line.

i. Railroad pen.—This pen is used for inking double (parallel) lines and is always used with a guide such as the edge of a T-square, triangular, or curve (fig. 15 ⑥).

j. Straightedges.—Used for drawing straight lines, these are usually from 15 to 72 inches long. They are made of hardwood (generally maple), stainless or nickel-plated metal, or translucent material such as xylonite. Some wooden straightedges have transparent edges. Straightedges have either square or beveled edges.

k. Beam compass.—Beam compasses are used when the radius to be drawn, or the distance to be laid off, exceeds the range of the ordinary compass or dividers. Beam compasses consist of three principal parts: a steel point; an interchangeable pen, pencil, and needle point with micrometer adjustment; and one or more bars, 18 to 70 inches long. These bars, to which the two first-named parts are fastened (fig. 16), are of hard wood or of tubular metal with interlocking sections (fig. 17).

l. Curves and splines.—(1) Irregular curves (fig. 18) are made of the same materials as triangles. They are used for drawing curves that cannot be drawn with a compass. Such irregular curved lines usually pass through a number of established points, and the edge of the irregular curve is placed so as to pass through as many points as possible.

(2) Splines (fig. 19) are flexible strips of wood or metal capable of being bent to form long, irregular curves. They are held in shape with weights while lines are drawn along the edge which is unobstructed by the weights. Splines have been superseded to some extent by adjustable metal curves consisting of a narrow steel band edge and a sliding bar encased in a steel coil to insure stability and flexibility.

m. Protractors.—Protractors are used to plot or to measure angles. They are made of wood, celluloid, or metal. The latter are the most satisfactory and come in various sizes, the smallest of which are graduated into single degrees, while the largest have verniers attached to permit the plotting or measuring of angles to single minutes of arc. The usual form is a semicircular arc graduated in degrees from 0° to 180°. The center of the graduated arc is marked so that it may be placed upon the vertex of the angle to be measured or laid off, with

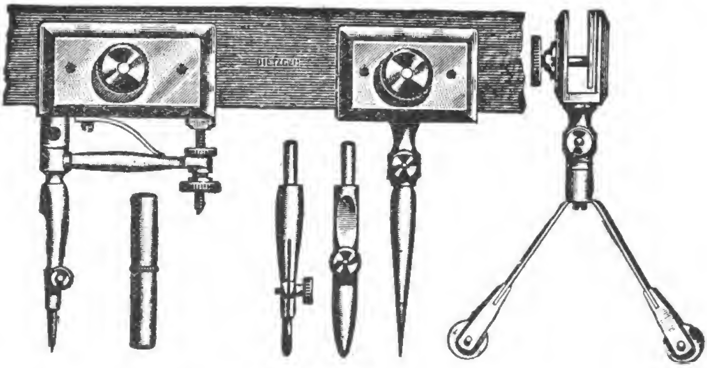


FIGURE 16.—Beam compass.

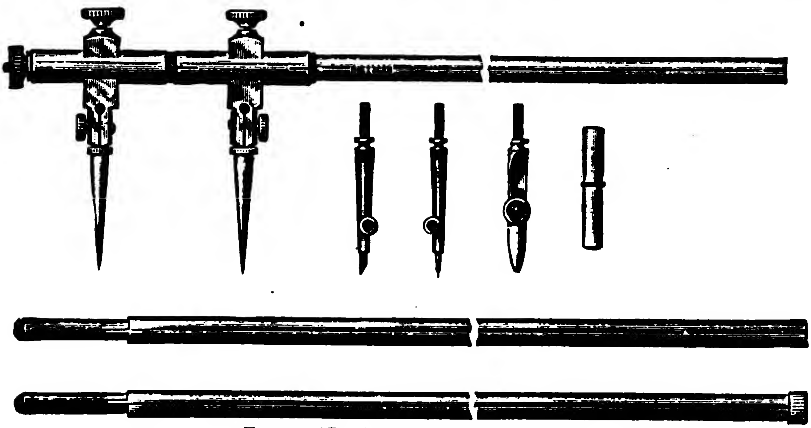


FIGURE 17.—Tubular beam compass.

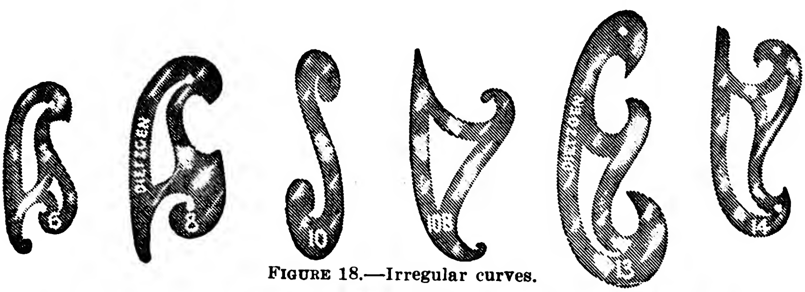


FIGURE 18.—Irregular curves.

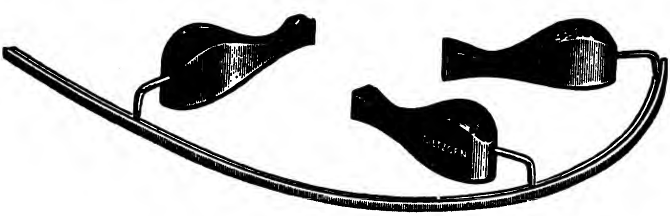


FIGURE 19.—Splines (flexible curves).

0° of the scale on one leg of the angle. The required number of degrees can be read or marked on the paper in prolongation of the division. Figure 20 shows a semicircular protractor; figure 21, a circular protractor with a vernier reading to 2½ minutes. Various combinations of protractors and scales of transparent material (fig. 22) are in use.

n. Special lettering pens.—Special lettering pens to enable any draftsman, with or without experience, to letter drawings, plans, and maps quickly with neatness and correctness are regular equipment of nearly every drafting room. These lettering pens may be divided into two classes: one class embracing such pens as the "Payzant" (fig. 23) or "Speedball" (fig. 24), which assure an even stroke; the other class including those which employ guides or templates producing letters and numerals with an even line and to uniform size, such as the "Wrico" or "Leroy" lettering guides (figs. 25 and 26). All these pens come in different sizes for any thickness of line and size of letter ordinarily used on drawings.

o. Pantograph.—The pantograph is an instrument for copying drawings to the same, a larger, or a smaller scale. The theory is based on the similarity of movement resulting in a parallelogram jointed at all four corners and secured at a prolongation of one side. The pantograph consists essentially of four bars (fig. 27 ①) which for any setting must form a parallelogram. Holes are provided in the arms at certain measured intervals by means of which the instrument can be set to give any desired ratio of enlargement or reduction. For accurate work a suspended pantograph (fig. 27 ②) with metal arms should be used.

p. Planimeters.—(1) Planimeters are designed to determine the number of square units (square feet, square meters, etc.) of areas with irregular boundaries, such as are used in earthwork computations. The tracing arm of the planimeter is set to the desired scale, and the tracing point is placed at any convenient point on the boundary of the area to be measured. The initial reading of the planimeter is then recorded, and the tracing point is carefully guided around the entire boundary of the area back to the starting point. Another reading is then recorded. The area is obtained by multiplying the difference between these readings by a factor obtained by calibration. The polar planimeter (fig. 28) is the type most used.

(2) Figure 29 shows a rolling disk planimeter. By means of a vernier and micrometer, accurate settings for any scale in United States standard measure can be obtained, with simple vernier unit values such as .001, .002, or .003 square inch. The angular motion of the tracer arm is about 30° left or right of the base. As the extent of

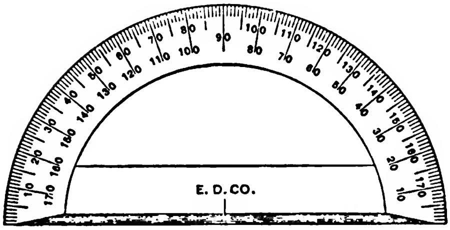


FIGURE 20.—Semicircular protractor.

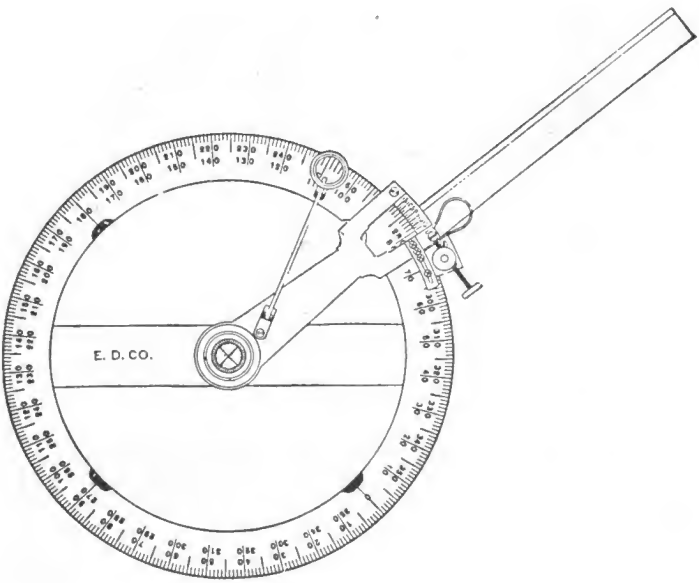


FIGURE 21.—Circular protractor.

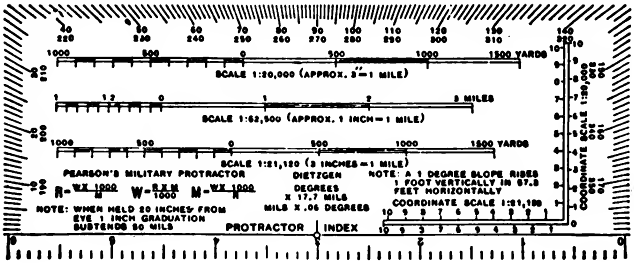
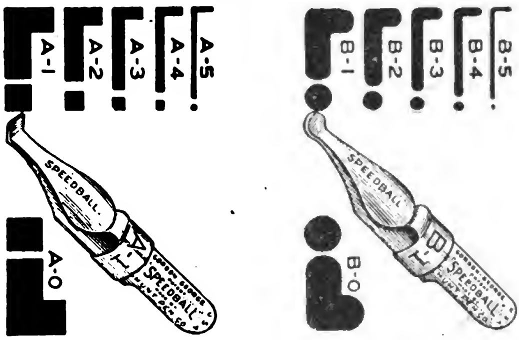


FIGURE 22.—Transparent protractor and scale.

FIGURE 23.—Payzant pen No. 8 with cork grip.



Style "A" Style "B"

FIGURE 24.—Speedball pens.

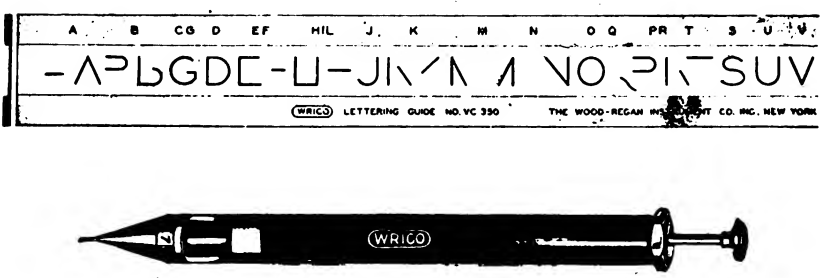


FIGURE 25.—Wrico lettering guide and pen.

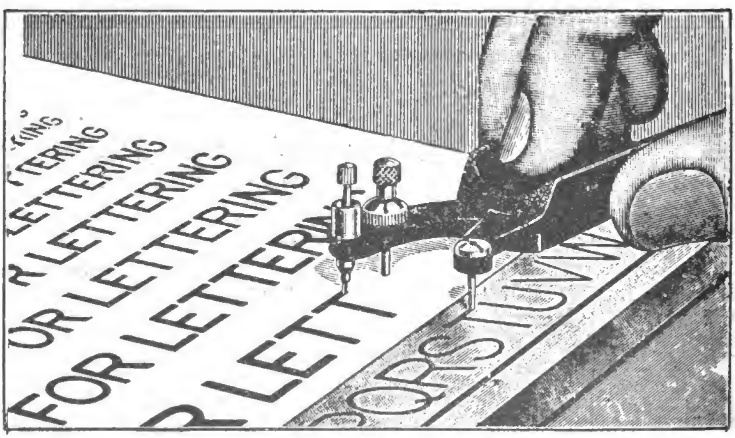
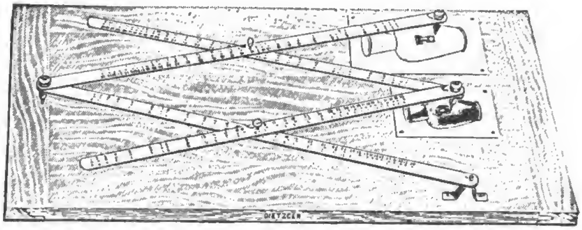
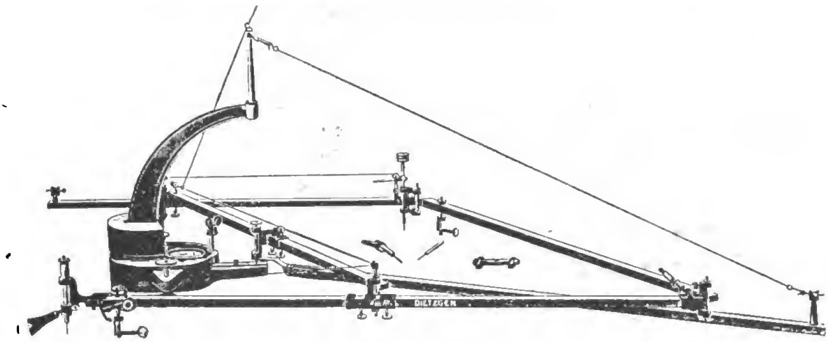


FIGURE 26.—Leroy lettering guide and pen.



① Ordinary type.



② Suspended precision type.

FIGURE 27.—Pantographs.

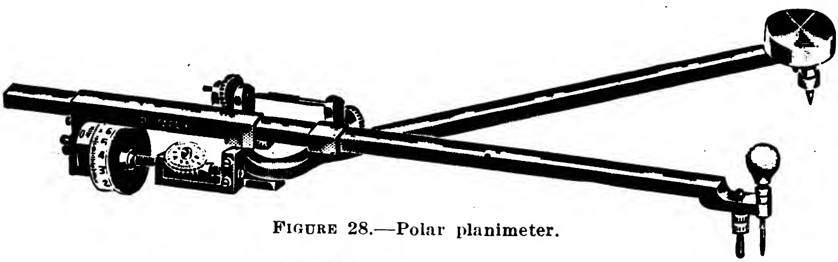


FIGURE 28.—Polar planimeter.

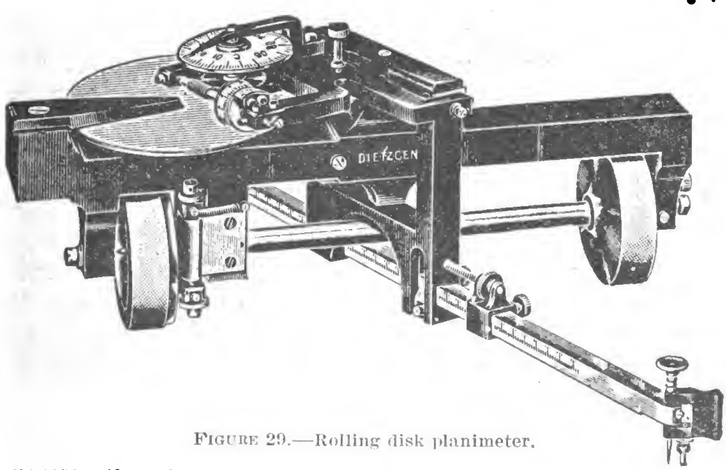
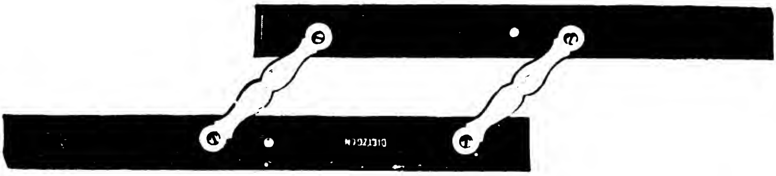


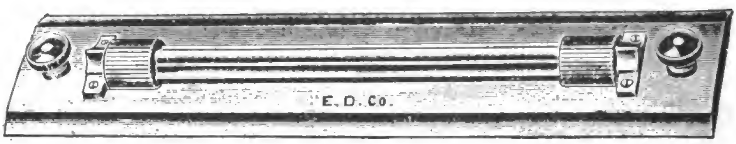
FIGURE 29.—Rolling disk planimeter.

the movement in the direction of the base is an unlimited area, any length and a width, which is not greater than the length of the extended tracer arm can be measured in one operation.

q. Parallel rules.—Figure 30 shows two types of parallel rules. These rules expedite the drawing of parallel lines and are from 9 to 24 inches long. The parallel rules (fig. 30 ①) are constructed with pivoted bars; the rolling parallel rules (fig. 30 ②) are made of metal.



① Adjustable type.



② Rolling type.

FIGURE 30.—Parallel rules.

r. Reading glasses.—Reading glasses, both magnifying and reducing are regular drafting room equipment. Magnifying glasses are often mounted on adjustable stands. Reducing glasses will show the draftsman how his work will look after it has been reduced in reproduction.

s. Slide rules.—Slide rules of various types, the most common of which is the 10-inch Mannheim (fig. 31), are an invaluable aid in making calculations and checking computations. For a detailed description of the Mannheim slide rule and its use, see TM 5–235.

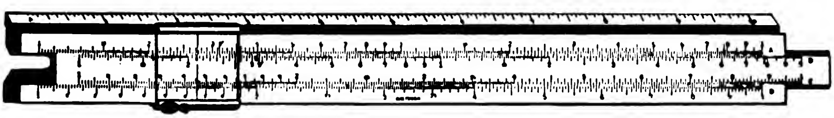


FIGURE 31.—Mannheim slide rule.

10. Special equipment.—*a. General.*—In drafting rooms where aerial photographs are utilized in the construction of maps, there is in use certain special equipment which improves the quality of the work and materially reduces the time required to finish a map. This equipment is described below.

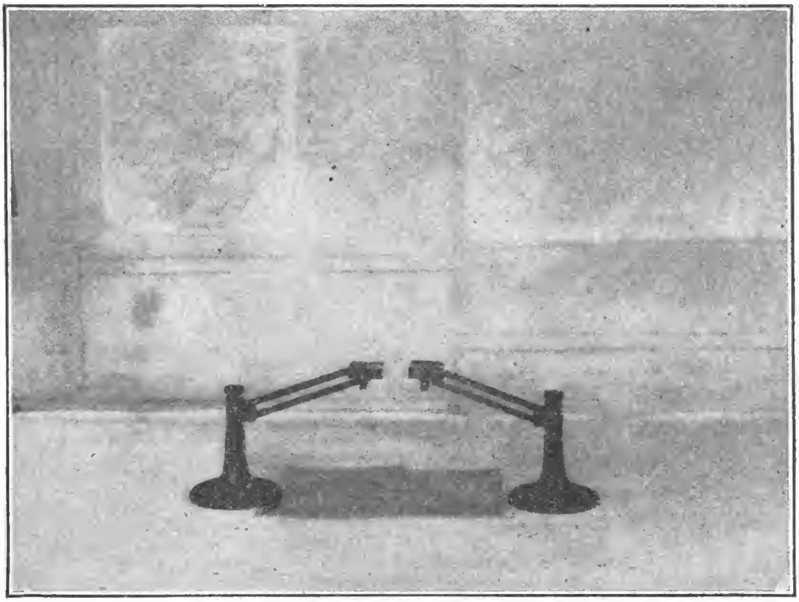


FIGURE 32.—Plain lens stereoscope (two reading glasses).

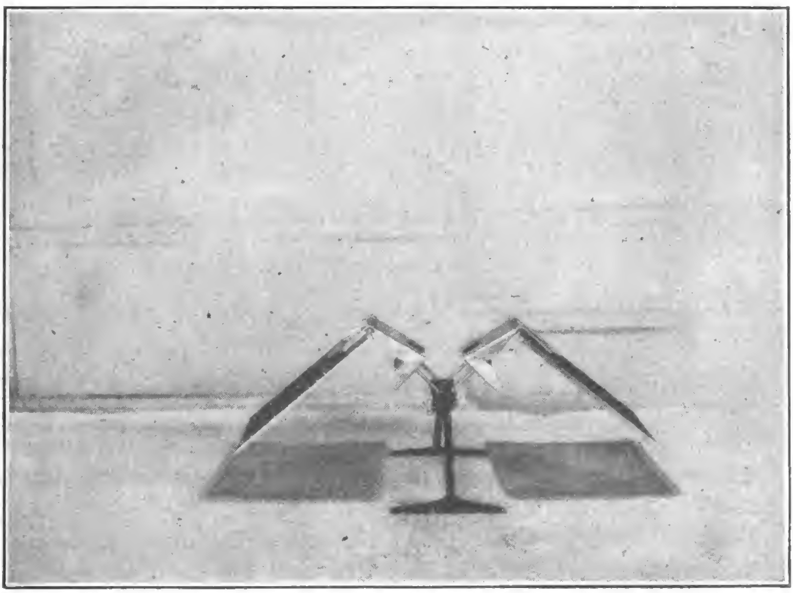


FIGURE 33.—Mirror stereoscope.

b. Stereoscopes.—Stereoscopes (par. 35) include a plain lens type (fig. 32); a mirror type (fig. 33); a lens-prism type (fig. 34); a prism diopter type, special reading glasses mounted in pairs (fig. 35); and a floating-mark type. The latter stereoscope is of the lens-prism type and is described in section XVII.

c. Stereo-comparagraph.—This is an instrument used in interpreting elevation and contours from aerial photographs. For a detailed description, see paragraph 82.

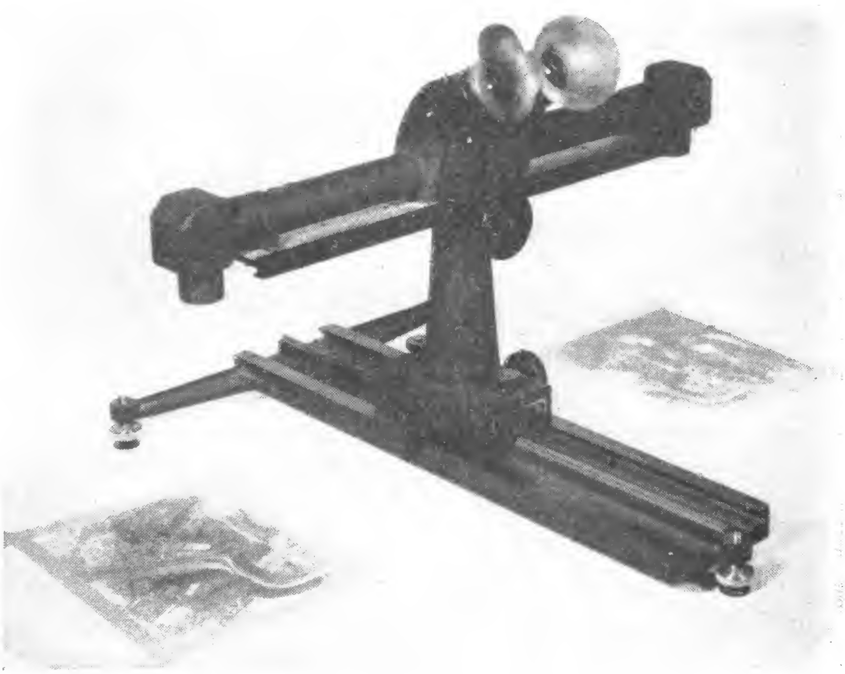


FIGURE 34.—Lens-prism stereoscope.

d. Templet slotter.—This machine (fig. 36) cuts (or punches) slots of a certain size in cardboard or film base templets to accommodate the templet studs described in *f* below. Paragraph 79*f* explains the use of the templet cutter.

e. Center punch.—The center punch (fig. 37) is used to punch the center holes in paper or in cardboard templets to accommodate the center stud (par. 79).

f. Templet studs and pins.—Templet studs are made of bronze or composition material, such as bakelite, and are used to hold overlapping aerial photographs in their correct positions (par. 79). The pins fit the hollow center of the templet studs and are used to mark

the correct positions of certain points of the aerial photographs, usually on the underlying control sheet. (See fig. 38.)

11. Materials.—*a. Drawing paper.*—(1) Paper for pencil drawings should have sufficient grain to take the pencil, be agreeable to

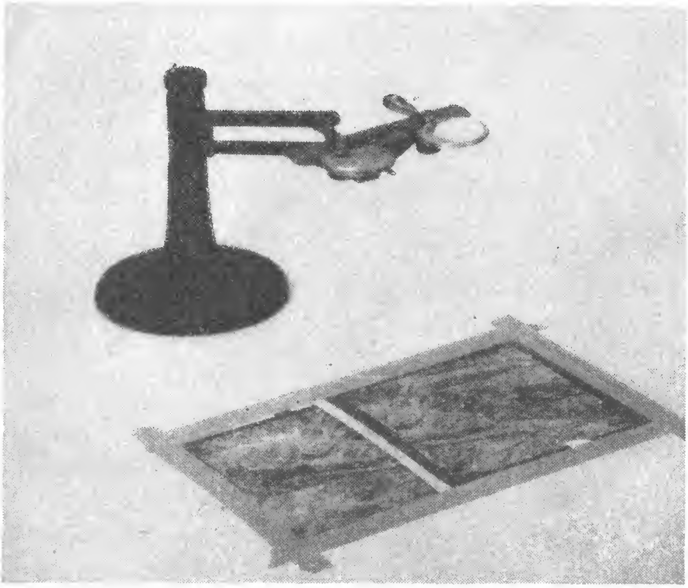


FIGURE 35.—Prism diopter stereoscope.

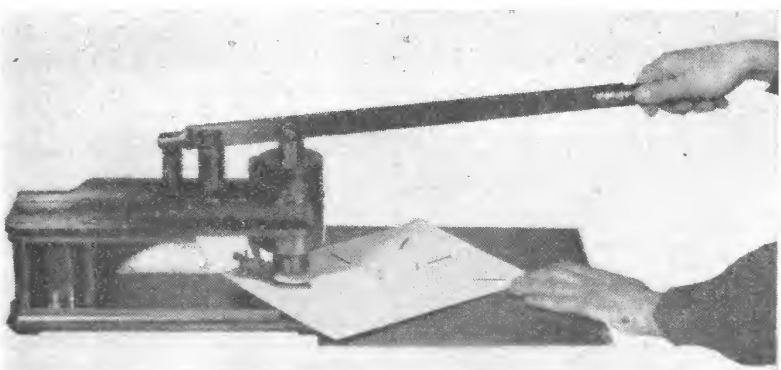


FIGURE 36.—Templet slotter.

the eye, and hold its surface under erasing. A good grade of cream detail paper meets these requirements and is used in most drafting rooms. Paper is furnished in rolls or in sheets cut to standard sizes. To avoid cutting and curling, it is best to use the sheet paper if proper storage facilities are available. Drawing paper should not be

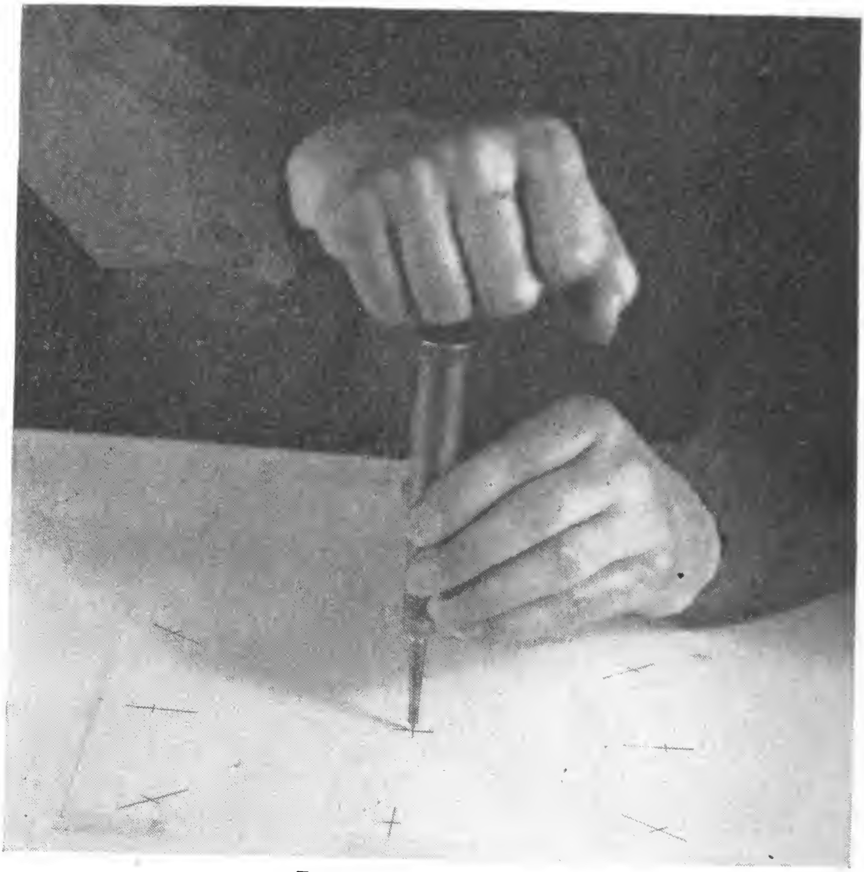


FIGURE 37.—Center punch.

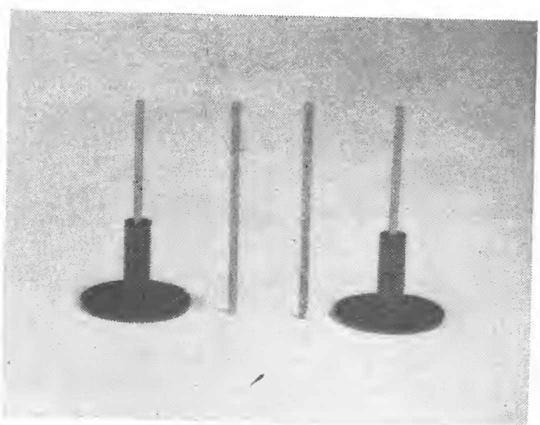


FIGURE 38.—Templet studs and pins.

folded. If the drawing is left on the board overnight, it should be covered with a large sheet of paper to protect it from dust and dirt. For large plots or drawings, double mounted drawing paper or drawing paper mounted on muslin is used.

(2) For precise work requiring extreme accuracy, drawing paper mounted on metal may be used. If such paper is required and is not readily available it may be made as follows:

Obtain zinc or aluminum lithographic sheets which have been discarded as unfit for reproduction purposes. These will be quite suitable if freshly grained. The paper should be the best white or near-white ledger stock available, of a size 2 inches longer each way than the metal. Sphinx paste or equal may be used. The paste is thinned with water if necessary. The paper is sponged with water on the side to be glued to the metal for about 30 minutes until it becomes quite pliable. The glue is then applied to the paper, and the paper is placed smoothly over the metal. A clean squeegee is used to smooth the paper and squeeze out the excess glue. A sheet of the same paper is then applied to the other side of the metal in the same way. The mounted sheet is hung on edge and allowed to dry for 24 to 48 hours, after which the edges are trimmed and bound with cloth tape.

(3) Smooth metal sheets coated with suitable paint, such as white "duco," are used to some extent for original drawings or maps that are to be printed in more than one color.

(4) Special ruled drawing papers, called cross-section paper (fig. 39) and profile paper (fig. 40), are used extensively as explained in paragraphs 54 and 55.

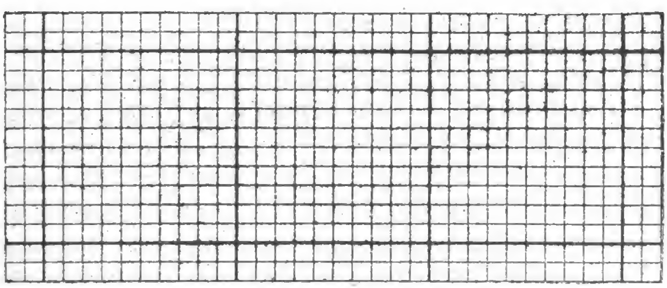


FIGURE 39.—Cross-section paper, 10 by 10 to the inch.

b. Templets.—Templets for use in aerial photographic work should be of tough, firm, light-colored cardboard, preferably 3-ply, with a slick playing-card surface.

c. Tracing paper, tracing cloth, and film base.—(1) These materials must be sufficiently transparent for the purpose intended. Tracing paper or vellum, either white or buff, is frequently used for pencil tracings such as shop drawings. For topographical drawings and aerial photomapping, use should be made of the best tracing paper available.

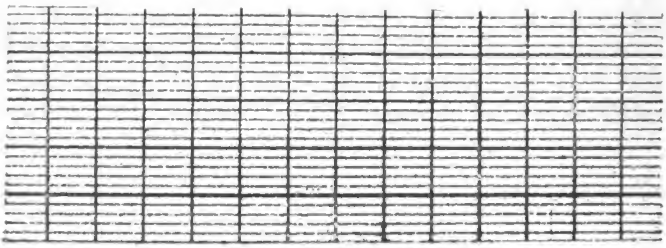


FIGURE 40.—Profile paper, 4 by 20 to the inch.

(2) Tracing cloth is made transparent by the application of a starch preparation. For this reason, water will ruin the surface and spot the copy made from it. The tracing should be protected from perspiration by keeping a sheet of blotting paper over the part not being worked on. It should always be covered at night if left on the table. The dull side of the tracing cloth should be used because it receives ink better. Before beginning work, it should be dusted with powdered chalk or pounce (*f* below) and rubbed lightly with a cloth to remove traces of grease which prevent the flow of ink from the pen. Tracing cloth is sensitive to atmospheric changes and often expands overnight. It should be thoroughly seasoned before use by subjecting it to the normal temperature of the drafting room for several weeks. Ruled tracing paper and tracing cloth are used for cross-section and profile tracing. For precise work, such as control plots, etc. (pars. 68, 78, 79, and 87), nonshrinkable film base is used. This film base comes in sheets or 100-foot rolls and because of its high cost will ordinarily be available only for work requiring hairline accuracy. However, every student should be given a problem which includes tracing of detail onto film base so that he will become accustomed to its almost nonporous surface. Film base should be slightly grained on one side, the grained side to be used for the drawing. If ungrained film base is used, it must be prepared by rubbing the drawing side with powdered pumice or a similar abrasive. The drawing side must be thoroughly cleaned before starting the tracing.

d. Pencils.—Pencils (black) for drawing are graded as follows:

Soft—6B, 5B, 4B, 3B, 2B, B, and HB.
Medium—F, H, 2H, 3H, and 4H.
Hard—5H, 6H, 7H, 8H, and 9H.

The draftsman generally uses two pencils: a hard pencil for line work and a soft pencil for lettering and sketching. The harder the pencil the more difficult it is to use properly. The beginner has a tendency to bear down too hard on the pencil and cut tracks in the paper; therefore, until the required lightness of touch is acquired, the beginner should use a relatively soft pencil; i. e., a 2H for lettering and a 3H or 4H for line work. When the necessary skill has been obtained, the draftman may use a 6H or 7H for line work and a 4H for lettering, thereby saving time by not being required to sharpen his pencil so often and by making lines that do not rub or smear.

e. Pen points.—Pen points for freehand lettering are made like the ordinary writing pen and are manufactured by a number of firms

LEONARDT 516 F
HUNT 512: Gillott 1032
Gillott 404: Spencerian No. 1
Gillott 303 For very fine lines Gillott 170 and 290

FIGURE 41.—Width of stroke of lettering pens.

and in a great variety of styles. Of those illustrated in figure 41 (shown by lettered names), the Gillott 303, Gillott 404, Hunt 512, and Leonardt 516 F, and the ball point fill the requirements of most draftsmen. Gillott's lithographic crow-quill pen is used extensively by most draftsmen for work on film base.

f. Pounce.—Pounce is a finely dusted powder used to rub tracing cloth so that the ink will more readily adhere to the prepared surface.

g. Drawing ink.—Drawing ink is furnished in two forms: liquid ink, in bottles from ¾ ounce to 1 quart, and stick ink, usually about ½ by ½ by 3 inches in size. Formerly all good drawings were made with chinese or india stick ink rubbed up in water to secure a black opaque liquid. Most draftsmen now prefer the bottled ink because of its convenience. Black, liquid, drawing ink contains finely ground carbon in suspension. For this reason it is necessary to shake the bottle before using. Waterproof ink contains shellac. The smaller bottles are provided with quill or glass tube fillers. Figure 42 shows

a popular ink bottle holder with special bottle top and quill. Liquid ink is furnished commercially in all colors. In using india ink in warm weather, a few drops of acetic acid should be added to keep flies from eating it off the paper. The ink used in tracing should be kept corked at all times to prevent thickening. The bottle is provided with a quill filler attached to the cork so that it is easy to form the habit of corking the bottle after filling the pen. The ink bottle should be set on a blotter away from the tracing to avoid ruining the drawing through accident. Water should never be used to dilute waterproof drawing ink. Ink once frozen is useless.

h. Tacks and tape.—Thumbtacks to hold paper in place while tracing or drawing upon it come in various sizes, the most common hav-

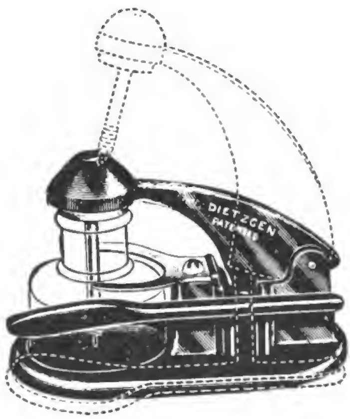


FIGURE 42.—Ink holder with special bottle top and quill.

ing a head about ½ inch in diameter. A more practical way to fasten paper or photographs to the drawing board or table is with scotch tape which can be removed without affecting the paper. This tape comes in convenient sizes, the ¾ inch width probably being best for all-around purposes.

i. Rubber cement.—Rubber cement is a liquid adhesive composed of rubber (caoutchouc) and a solvent, usually naphtha or benzol. It is used for mounting photographs (par. 73) and drawings, and being both nonwrinkling and quick setting it is much more satisfactory than other adhesives.

j. Sandpaper pads.—Sandpaper pads, sometimes referred to as pencil pointers, are used to point the lead of drawing pencils (par. 13*a*).

k. Oilstones.—A small, finely grained oilstone should be part of the equipment for every drafting room, as each draftsman will have to

sharpen his ruling pens and the points of compasses and dividers (par. 14*a* and *b*).

l. Erasers.—The pencil erasers should be large with a beveled end. In addition, it is advisable to have an art gum or sponge eraser to clean fingerprints and smudges from the drawings. Art gum should not be used on tracings.

m. Steel erasers.—Steel erasers are sometimes preferred to remove the surface ink from a drawing before using a rubber eraser. Many draftsmen prefer the use of an engraver's needle. This is a strip of highly tempered steel encased in wood about the size of a pencil and may be obtained in different sizes; it is one of the handiest tools a draftsman may use for removing small spots or lines. Razor blades serve a similar purpose.

n. Erasing shields.—Erasing shields of metal or some transparent material are used to confine the rubbing to the area actually to be corrected or cleaned and prevent the surface of the paper or cloth from buckling while erasures are being made.

Section III

INSTRUCTIONS IN USE AND CARE OF EQUIPMENT

12. Linear guides.—Linear guides include all items of instruments and equipment which serve as guides for making straight or irregular curved lines with pencil or pen.

a. T-*squares and triangles.*—(1) T-*squares.*—The inside edge of the head is placed against the working edge of the drawing board. One may be sure that the head of the T-square is in close contact with the board by listening for the little double click that occurs as it comes against it. The T-square is moved up and down on the board (fig. 43). The fingers of the left hand draw the T-square against the edge of the board, and when in position for drawing a line the T-square is held firmly in the same manner, and, in addition, the heel of the left hand is placed upon the board. Only the upper edge of the T-square should be used in drawing horizontal lines. This edge may be tested for alinement by drawing a sharp line along it and then reversing the

T-square end for end and checking the same edge against the drawn line. Only a steel straightedge should be used as a guide for cutting paper.

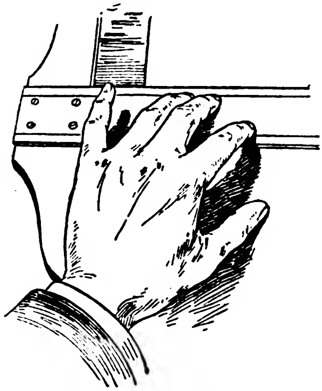


FIGURE 43.—Method of holding T-square.

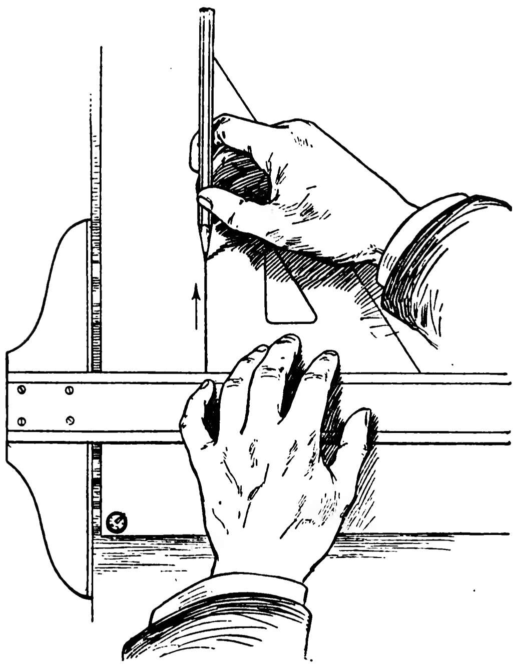


FIGURE 44.—Method of holding triangle.

(2) *Triangles.*—The triangle in use should be held in close contact with the upper edge of the T-square (fig. 44), the fingers of the left hand resting on both the triangle and T-square and the heel of the left hand on the board. To test the 90° angle of the triangle draw a perpendicular line, then reverse the triangle (fig. 45). The line should

coincide with the edge in the second position. The lettering triangle is used to draw correctly spaced guide lines for lettering.

b. Curves and splines.—After the principal points (shape) of the irregular curved line have been determined and plotted, that portion of

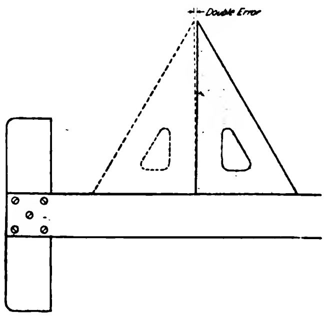


FIGURE 45.—Testing a triangle.

the irregular curve which joins the greatest number of plotted points is selected and placed in position. When accuracy is required it may be necessary to draw the line as a series of short, tangential segments. Considerable practice is required to produce a perfectly smooth curved line, and a careful fitting of the guiding curve is necessary. If splines

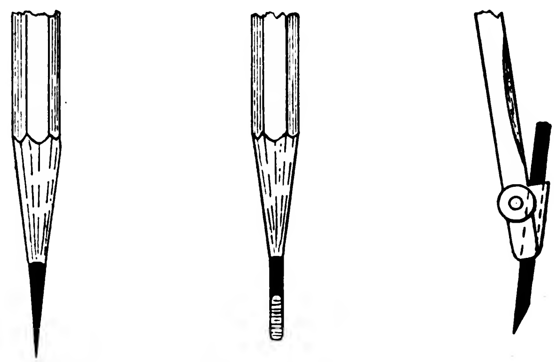
FIGURE 46.—Drawing a curved line.

or adjustable metal curves (par. 91) must be used to draw an irregular curved line, they are laid and adjusted to the plotted points, and after being weighted down, where necessary, the line is drawn, care being taken to see that the splines (or curves) do not move before the line is completed. (See fig. 46.)

c. Straightedges.—Straightedges are used as a guide in drawing straight lines connecting any two predetermined points. A straightedge is more frequently used in topographical drafting than the T-square.

d. Parallel rules.—Parallel rules (par. 9*q*) are used for the purpose of drawing any number of parallel lines by scaling only one set of spacing points. The same results may be obtained by the use of two triangles.

13. Pencils and pens.—*a. Pencils.*—The condition in which a draftsman keeps his pencils greatly influences the character of his finished work. Pencils must be sharpened to suit the purpose for which they are to be used. For best work they may be sharpened to a long conical point for lettering or freehand drawing; a wedge-shaped knife edge for line work; a chisel point for use in compasses (par. 14*c*). (See fig. 47.) In sharpening a pencil the wood at the end opposite to



① Conical point. ② Wedge point. ③ Chisel point.

FIGURE 47.—Pencil points.

the one indicating the hardness is cut away with a knife, exposing about ⅜ inch of lead, which is then sharpened as desired on the sandpaper pad (fig. 48). Frequent resharpening of the point is necessary for accurate work. Some experienced draftsmen sharpen a pencil with a wedged edge at one end and a conical point at the other. This, of course, implies the ability to use a fairly hard pencil for lettering. After the lead has been sharpened to the desired point it should be polished on a piece of scrap drawing paper to remove the rough bur and then wiped with a piece of cloth.

b. Lettering pens.—Lettering pens are used for single-stroke freehand lettering and for inking irregular lines and symbols without the use of a guide. Rules for the selection and employment of such pens are as follows:

(1) Choose a pen that is suited to the proposed work, according to descriptions contained in paragraph 11*e*.

(2) For inking single-stroke lines use a pen which will give the width of stroke desired.

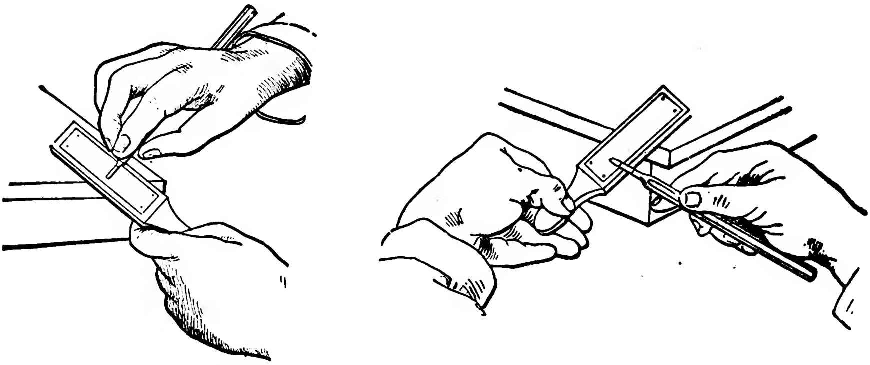


FIGURE 48.—Sharpening wedge point and conical point.

(3) Hold the pen as in writing; do not cramp the fingers by squeezing the holder too tightly (fig. 49).

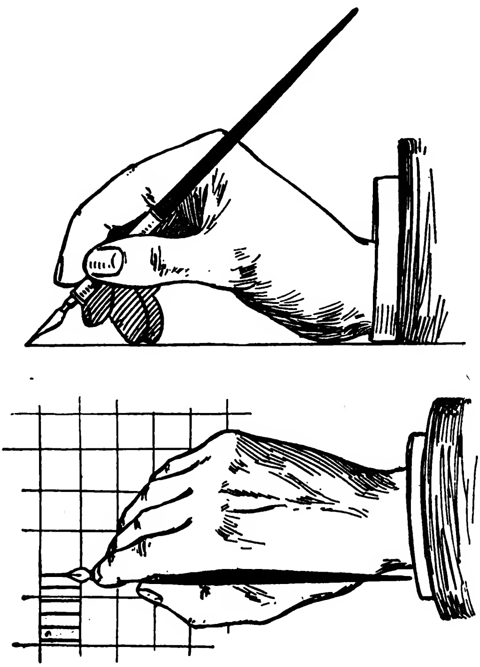


FIGURE 49.—Holding lettering pen.

(4) Make all strokes with a steady, continuous motion, exerting the same pressure on the point at all times.

(5) For large single-stroke lettering, use a ball point, speedball, or Payzant pen.

(6) Break in any pen before using by removing the oil coating either by wetting and rubbing or by holding in a match flame for a few seconds.

(7) Clean the point frequently.

(8) Fill the pen by using the quill instead of dipping in the ink bottle.

c. Special pens.—Payzant pens are preferred by many draftsmen, especially for making larger letters, as the point of these pens produces the same width of line no matter in what direction it moves over the paper. These pens (fig. 23) are held like the ordinary writing pen so that the marking point makes full contact with the paper. The cuplike reservoir holds enough ink to make frequent refilling unnecessary. Cleaning is accomplished by pulling a small strip of thin paper through the opening between the nibs, being careful not to spread and distort them. Alcohol is a good cleaning solvent when used before the ink has dried on the point. Speedball pens, used in ordinary penholders, are suitable for freehand lettering and produce lines similar to those drawn by Payzant pens.

d. Mechanical lettering pens.—For quick, perfect lettering of all sizes, mechanical lettering pens are an aid to the inexperienced draftsman. Their disadvantages are in the production of lettering devoid of character and the prevention of skill attainment by students. Freehand lettering, when well done, is faster and more generally appealing to the eye.

14. Drawing instruments.—*a. Ruling pens.*—Directions for using and sharpening the ruling pen are as follows:

(1) Be sure the pen is clean, and set the nibs to the desired opening.

(2) Fill the pen with the filler, holding the pen away from the drawing. Put in the opening between the nibs not more than from $\frac{3}{16}$ to $\frac{5}{16}$ inch of ink, depending upon the opening. Carefully remove any ink from the outside of the blades. Make a trial line on scratch paper to see if the pen is set correctly.

(3) Hold the pen so that both points touch the paper and the side of the lower blade rests against the edge of the T-square.

(4) Draw lines with a whole-arm movement, resting the tips of the third and fourth fingers on the T-square, and keeping the angle of inclination of the pen constant.

(5) Just before reaching the end of the line, stop the guiding fingers on the T-square and finish with a finger movement.

(6) Draw short lines with finger movements alone.

(7) When the end of the line is reached, lift the pen vertically and move the straightedge away.

(8) In drawing intersecting lines watch the intersection, and if the ink starts to run down the intersected line toward the straightedge lift it quickly from the drawing.

(9) If the ink refuses to flow, draw the point quickly over a piece of scratch paper.

(10) The pen should be cleaned during use by forcing a piece of blotting paper through the nibs without disturbing the setting. Before putting the pen away for a considerable period it should be

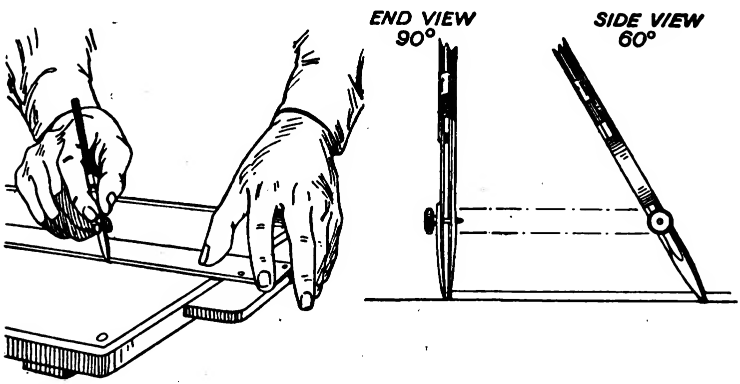


FIGURE 50.—Drawing line with ruling pen.

cleaned with hot water or alcohol and given a light coating of oil. This oil should be removed before attempting to use the pen again. (See fig. 50.) Figure 51 illustrates what happens when the ruling pen is not operated properly.

b. Sharpening drawing pens.—Ruling pens and other similar line-drawing pens must be kept sharp and properly pointed. Nibs of these pens will wear unevenly (see heavy black lines in fig. 52) and must be reshaped and resharpened as shown by the dotted lines in the figure. To sharpen drawing pens properly, proceed as follows:

(1) Put one or two drops of light oil on the oilstone.

(2) Screw the nibs together until they touch.

(3) Hold the pen as in drawing a line and draw the points back and forth across the oilstone, starting the stroke with the handle at about 30° with the stone, and swinging it up to and past the perpen-

dicular as the stroke proceeds and down to 30° at the end of the stroke.

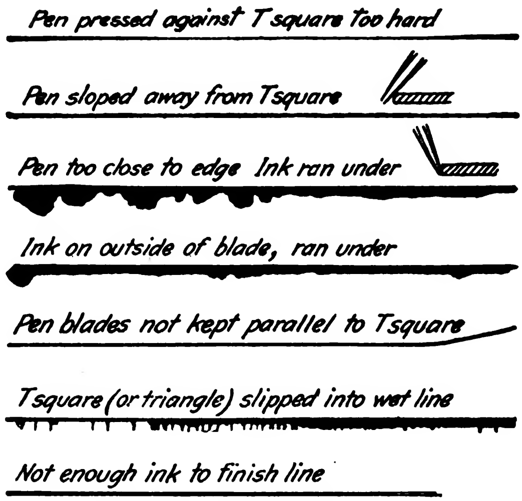


FIGURE 51.—Faulty lines.

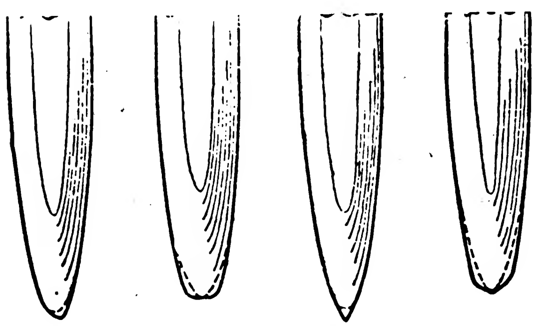


FIGURE 52.—Proper shape of points.

(4) Open the nibs slightly when they have been brought to equal shape and strength.

(5) Hold the pen at a slight angle with the stone (fig. 53) and sharpen each point in turn until the bright spot at the end has just disappeared.

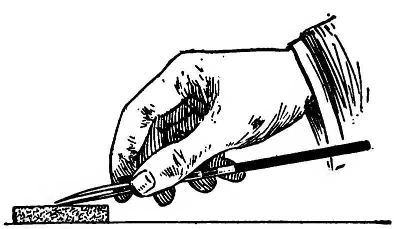


FIGURE 53.—Sharpening ruling pen.

(6) Use a slightly rocking motion in sharpening to conform to the shape of the nib.

(7) Test the nibs by drawing a line on paper without ink. The pen should not cut the paper. Then test by drawing very fine lines with ink.

c. Compasses and dividers.—(1) The compass (fig. 11) is used to draw circles or arcs with pencil or ink. When drawing arcs and tangents it is best to draw the arc first and then draw the lines connecting them.

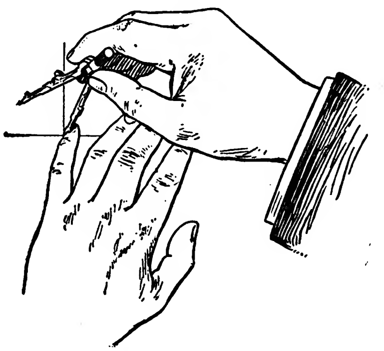


FIGURE 54.—Centering the compass.

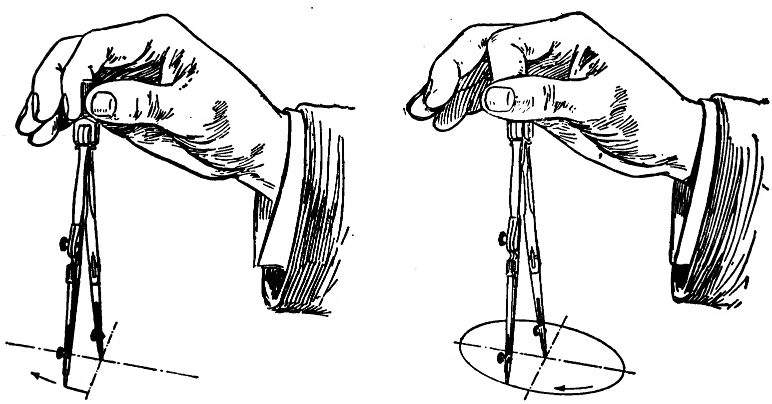


FIGURE 55.—Starting and completing a circle.

(2) To draw a circle, guide the needle point to its position (fig. 54), and bend the legs at their knuckle joints so that the points will be perpendicular to the paper. Press the point lightly into the paper to avoid making large holes in the drawing. Grasp the handle between the thumb and forefinger of the right hand, inclining it slightly in the direction of the line, and in one sweep draw the circle, rolling the handle between the thumb and forefinger (fig. 55). Do not go over the circle more than once unless the line is to be widened.

(3) To ink circles or arcs with the compass pen proceed as follows: Fill the compass pen like the ruling pen. Set the radius by lightly pricking the needle point, in the position of the center, and moving the pen leg by hand or screw. Move the pen down very close to the paper without touching it and set the arc off accurately. Swing the arc in the same manner as when drawing in pencil. In making two arcs tangent to each other, make the center lines of each ink line tangent (fig. 56).

(4) The divider (fig. 12) is used to mark finely certain points on a drawing by measuring from some previously marked point or line. Guide one of the needle points of the divider, as shown in figure 54 for the compass, to the initial point and carefully set the other point of the divider (in proper alinement) in position, leaving a fine prick mark on the paper.

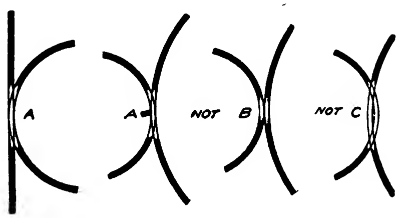


FIGURE 56.—Tangent arcs.

d. Bow spring instruments and drop pen.—(1) The manner in which bow spring instruments are used is the same as explained for compasses and dividers (*c* above).

(2) The drop pen (fig. 14) is used to draw small circles. It is filled like the ruling pen after being set to the desired radius. As the name implies, the pen drops (moves up and down) along a tiny shaft, ending in a needle point, which is held stationary at the top with the thumb and forefinger while the pen is held up with the middle finger. The circle is made by releasing the middle finger, the latter imparting a rotary motion to the pen which automatically drops and produces the circle. The pen can easily be lifted with the middle finger and the operation repeated over a new center. For inking small holes, say 1/8 inch in diameter, this pen is very valuable.

e. Swivel pens.—(1) The contour pen (fig. 15 ④) is used principally for inking contours (fig. 57). The pen, which must be held perpendicular to the plane of the paper, is attached to a rod that rotates in a metal handle, the manipulation of which enables the draftsman to follow the most intricate irregular curves. For very fine line work with loops of small radii, it will be necessary to use

ordinary lettering pens as the contour pen tends to make sharp angles when the loops are small.

(2) The swivel road pen is used for inking curved roads or other features which are shown by two irregular parallel lines. It functions like the contour pen but, since two separate pairs of blades must be kept in touch with the paper while the ink flows freely, requires more skill in handling.

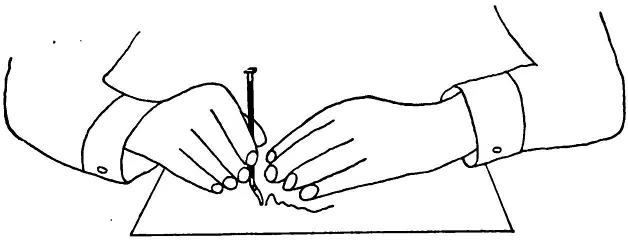


FIGURE 57.—Use of contour pen.

15. Measuring instruments.—*a. Scales.*—Scales are used to lay off distances (fig. 58). A hard pencil with a long, conical point should be used to mark the subdivisions and location of points. If possible the draftsman should use a true scale corresponding to the scale of the map, drawing, or photograph he is working on. If the

FIGURE 58.—Laying off distance with engineer scale.

proper scale is not available he should make one, in which case it is best to construct a plotting scale (fig. 85). Most drafting rooms have a supply of standard scales, such as 1:5,000, 1:10,000, etc., but must make their own nonstandard scales, as for instance those used in connection with aerial photographs. For laying off map projec-

tions or other large dimensional work requiring great accuracy, stainless or plated metal scales of sufficient length and subdivided as necessary for the work are used. When a true scale is not available for plotting distances, the distance to be plotted must be first converted into units of the scale that is to be used.

b. Beam compasses.—In using the beam compass (figs. 16 and 17), the attachment with the needle point should be placed on the beam at the left end of the bar and fastened securely. The pen or pencil attachment should then be placed in the approximately correct position, and after setting the needle point in the center of the circle the pen or pencil point attachment can be slid along the bar until it is at or near its exactly correct position. The hairspring adjustment, which

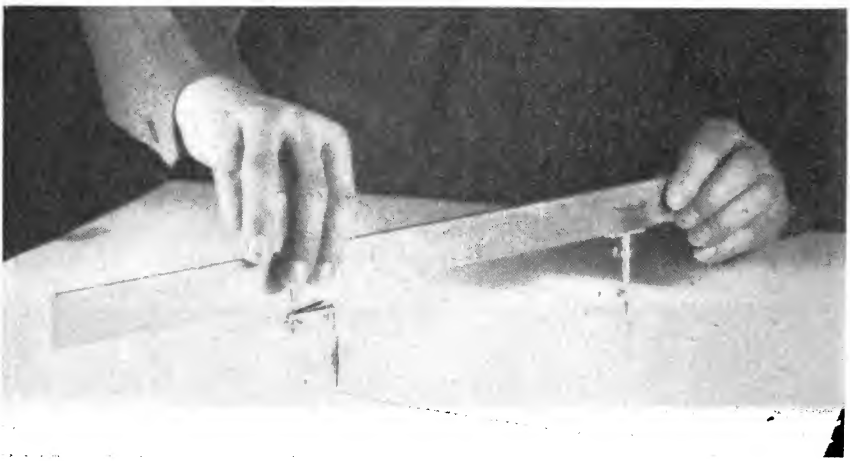


FIGURE 59.—Drawing an arc with beam compass.

most instruments have, enables the pen or pencil point to be moved slightly, if necessary, to its exact position. Figure 59 illustrates a proper way of holding the beam compass while making an arc or circle. Beam compasses are also used for laying off distances that are too long for the divider. In this case a second needle point in place of the pen or pencil point is used.

c. Proportional dividers.—Proportional dividers (fig. 15 ③) are useful in converting distances from one scale to another within the range of the instrument used. With it one can readily transfer positions from a map, photograph, or drawing to one of a different scale. Most of these instruments have divisions marked for linear measurements on one side and for circles on the other. Tests of these markings should be made before complete reliance is placed on them.

d. Protractors.—The principal uses of protractors are to lay off angles or plotting courses by them. Figure 60 illustrates the plotting of an angle of 44° from the left zero point of the protractor and an angle of 64° from the right zero point. In each case the protractor is laid with its edge *AB* along the previously drawn line *g–d* so that the center point *C* of the protractor falls on the vertex of the angle to be plotted. The point for the other leg of the angle (44° or 64° in this case) is then marked on the paper alongside the outer edge of the protractor as indicated. When a protractor of the type shown in figure 21 is used, it is laid on the paper so that its 0° and 180° marks coincide with the drawn line, and its center mark (the intersection of two cross lines on transparent material) is on the vertex of the new angle. The swinging arm or blade is then set, using the attached vernier, to coincide with the proper mark on the outside edge of the

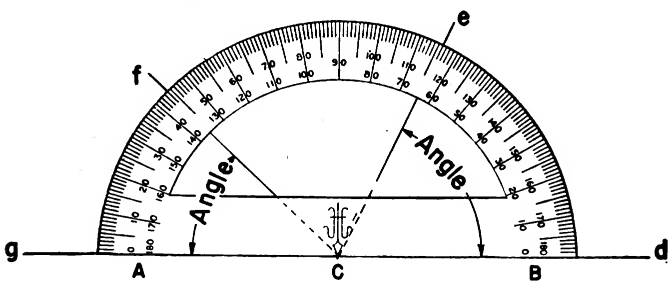


FIGURE 60.—Plotting angles with protractor.

divider, and a line is drawn along the beveled edge of the blade for the second leg of the new angle.

16. Pantographs.—*a. General.*—For accurate map work, only the best precision types of pantographs should be used. A booklet with instructions for using and setting up the instrument is furnished by the maker in each case; hence it is unnecessary to go into these preliminary details. However, there are some details relating to the use of the instrument that are usually not published. The most important of these are given in *b* below.

b. Calculations for setting from scales of map.—A saving of time results by disregarding the markings on the arms of the pantograph when making an original setting, and by adjusting the instrument according to the actual drawings. This method will automatically absorb any stretching or shrinking of the drawing or tracing paper. When stretching or shrinking has occurred and is found to be uneven after testing the paper both horizontally and vertically, the average should be figured and the pantograph set accordingly.

17. Planimeters.—The theory of the polar planimeter is that for a certain length of arm, in traversing a closed figure, the product of the length of the arm and the net roll of the wheel is representative of the area enclosed by the traverse of the movable point. When no instrumental constants for setting the planimeter are given, the following method may be followed to obtain the area of any irregular figure: Draw a 4-inch square and set the movable point at one corner of it. See that the reading is slightly above zero and note. With the fixed point outside the area, traverse the figure and record the reading. Do this three times thus getting three differences between the initial and final reading. Take the average of the three differences. Compute the true area of the figure to its plotted scale and calculate the ratio of the planimeter readings (differences) to the scale of the plotted area. The instrument can then be set to give the actual values for the area, or the constant obtained may be used to convert the readings into actual values for the area or areas to be measured. The rolling disk planimeter may be used in the same manner as the polar planimeter.

18. Special equipment.—*a.* The special equipment mentioned here is used in connection with aerial photographs for mapping (office work).

b. For directions in the use of the simple stereoscope see section VII.

c. For directions in the use of the stereo-comparagraph see section XVIII.

d. For directions in the use of the templet cutter, center punch, studs, and pins, see paragraph 79.

Section IV

BASIC DRAFTING INSTRUCTIONS

19. General.—Accuracy, legibility, neatness, clear-cut lines, good lettering, and ability to combine the various parts of a drawing into a pleasant appearing, orderly looking, and well-proportioned whole distinguish the work of an experienced draftsman from that of a novice. It is necessary for the latter, in order to become a good draftsman, to be well grounded in the proper use of drafting equipment

and to be thoroughly familiar with the fundamentals of good draftsmanship. The most important of these factors is the ability to draw accurately the various topographic signs and symbols and to label the different features of a map with their names correctly spelled, using well-proportioned and properly spaced letters. Misspelled words and names on an otherwise excellent map tend to cause doubt as to the accuracy of the other features shown thereon. The term "accuracy" as related to drafting, especially topographic drafting, means much more than the accuracy normally required of an experienced artisan such as a carpenter or tinsmith who measures and finishes his work within broad tolerances. A draftsman must be able to draw his lines so that a good eye cannot detect even the minute irregularities which may occur when extending an inked line, joining a tangent to an arc, or rounding off a corner.

20. Freehand lettering.—*a. General.*—(1) The appearance of a drawing or map depends largely upon its lettering. Letters of a particular style should always conform to a standard proportion for that style, i. e., the "I" is always the narrowest letter and the "W" the widest, with proportionate widths ranging between these two for the other letters. Different styles also vary as a whole. Styles narrow in their proportion of width to height are called "compressed" letters and are used when space is limited. Those wider than normal are called "extended" letters. The proportion of thickness of stem to the height of the letter varies. Letters with heavy stems are called "bold face" (or black face); those with thin stems are called "light face." Capitals "C," "G," "O," "Q," "S," if $\frac{1}{10}$ inch or larger, should extend a trifle above and below the top and bottom guide lines, in order to appear of equal height with the straight-line letters. In order to make the middle line in letters such as "B," "E," "H," "S," etc., appear to be well-balanced, it should be placed slightly above the middle.

(2) Single-stroke lettering forms letters in which the width of all lines is the width of one stroke of the pen. Therefore, for a desired height a pen must be selected which will give the necessary width of stroke. Single-stroke lettering is used almost exclusively for letters less than $\frac{5}{16}$ inch in height. It is the easiest and most rapid of all styles of lettering.

(3) Roman lettering is made up of letters consisting of two weights. The fine line is made with a single stroke and the heavy line is outlined and filled in with ink. All horizontal strokes are light, all vertical strokes are heavy except in "M," "N," and "U." Oblique lines with lower ends to the left are light (except in "Z"),

and those with lower ends to the right are heavy. The ends of most strokes are finished by small vertical or horizontal lines called "serifs," which are used to give a finished effect to the letters. They are joined to the body stroke by small curves or fillets.

(4) Gothic letters are of the same form as the single-stroke letters described above and are used for work over 5/16 inch high. These letters are usually drawn in block outline in pencil. In inking this penciled outline, keep the outside of the ink line on the pencil, otherwise the finished letter will be heavier than expected.

b. Styles of lettering and their uses.—(1) Single-stroke lettering, both vertical and slant, is used for dimensions, notes, and titles on working drawings, and on photographs and maps that must be finished rapidly. (See pars. 90*g* and 94*d*.) Single-stroke lettering when used on hasty, provisional, or battle maps may be arranged as follows:

(*a*) For States, counties, cities, etc.—all vertical capitals.

(*b*) For towns, villages, etc.—vertical capital initials, etc.

(*c*) For bodies of water, large rivers, etc.—all slanted capitals.

(*d*) For smaller streams—slanted capital initials, etc.

(*e*) Contour numbers—slanted; all others—vertical.

(*f*) For public works—small slanted capitals.

(*g*) For all other map features—small vertical capitals.

(*h*) For all marginal lettering—slanted capitals for title; slanted capital initials for remainder.

(2) Vertical gothic is used on maps to show hypsography: mountains, plateaus, etc., in capitals; and peaks, small valleys, and canyons in lower case with capital initials.

(3) Slant gothic is used to name public works: railroads, tunnels, bridges, etc., in capitals; and contour numbers in slant gothic numerals.

(4) Roman vertical is used to name the civil divisions and certain terrain features on a map: lakes, rivers, and bays in capitals only; and creeks, brooks, ponds, etc., in lower-case with capital initials.

(5) Vertical gothic, spurred, is used for all marginal lettering on maps.

c. Stroke technique.—(1) Single-stroke, lower-case, slanted letters are made on a slope of 2 to 5. Lower-case letters are always three-fifths the height of their corresponding capital letters; such lower-case letters as the "p," "g," etc., extend below the bottom line the same distance as capital letters extend above the top line of lower-case letters. Letters are made with a conical-point pencil rotated frequently in order to keep the point conical. The pencil is held easily, as in writ-

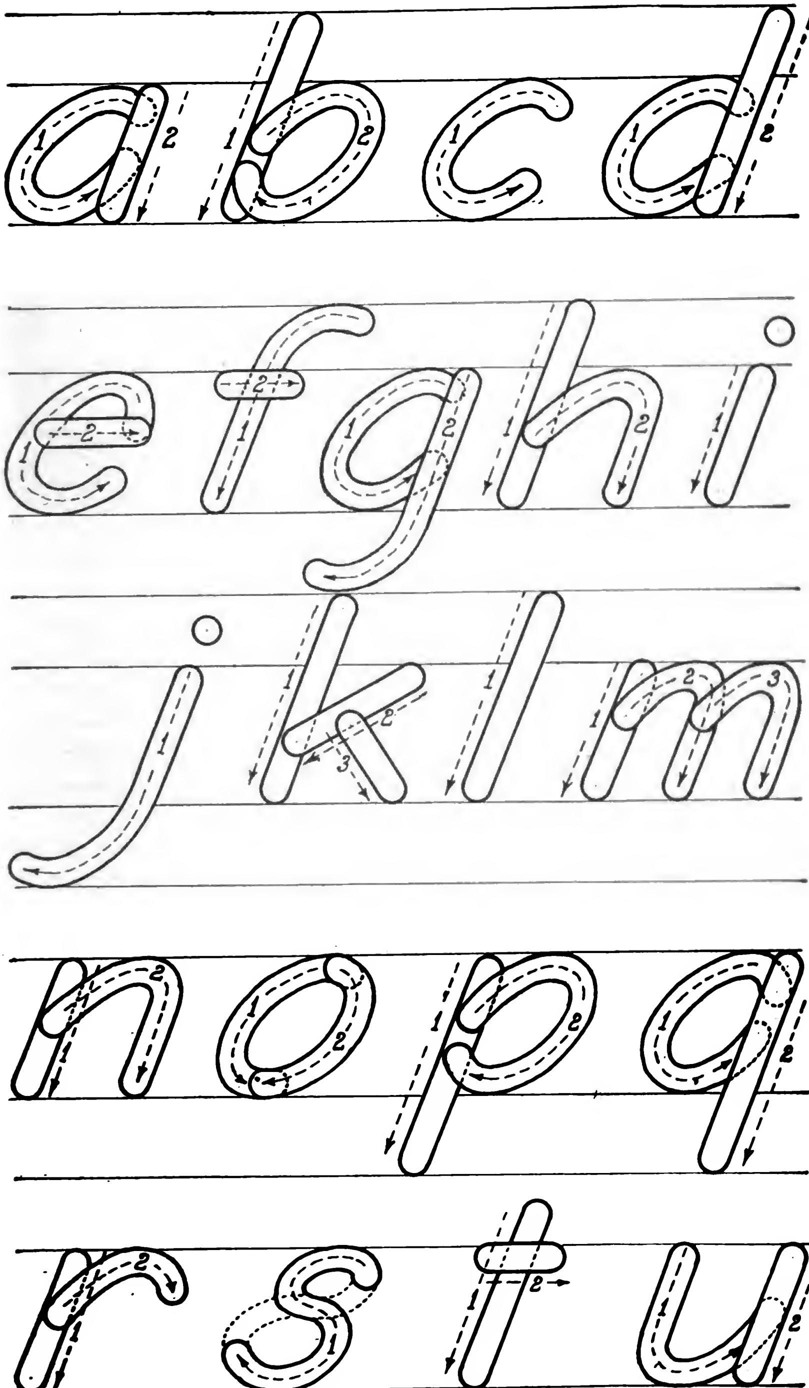


Figure 61.—Stroke technique—lower-case slant letters.

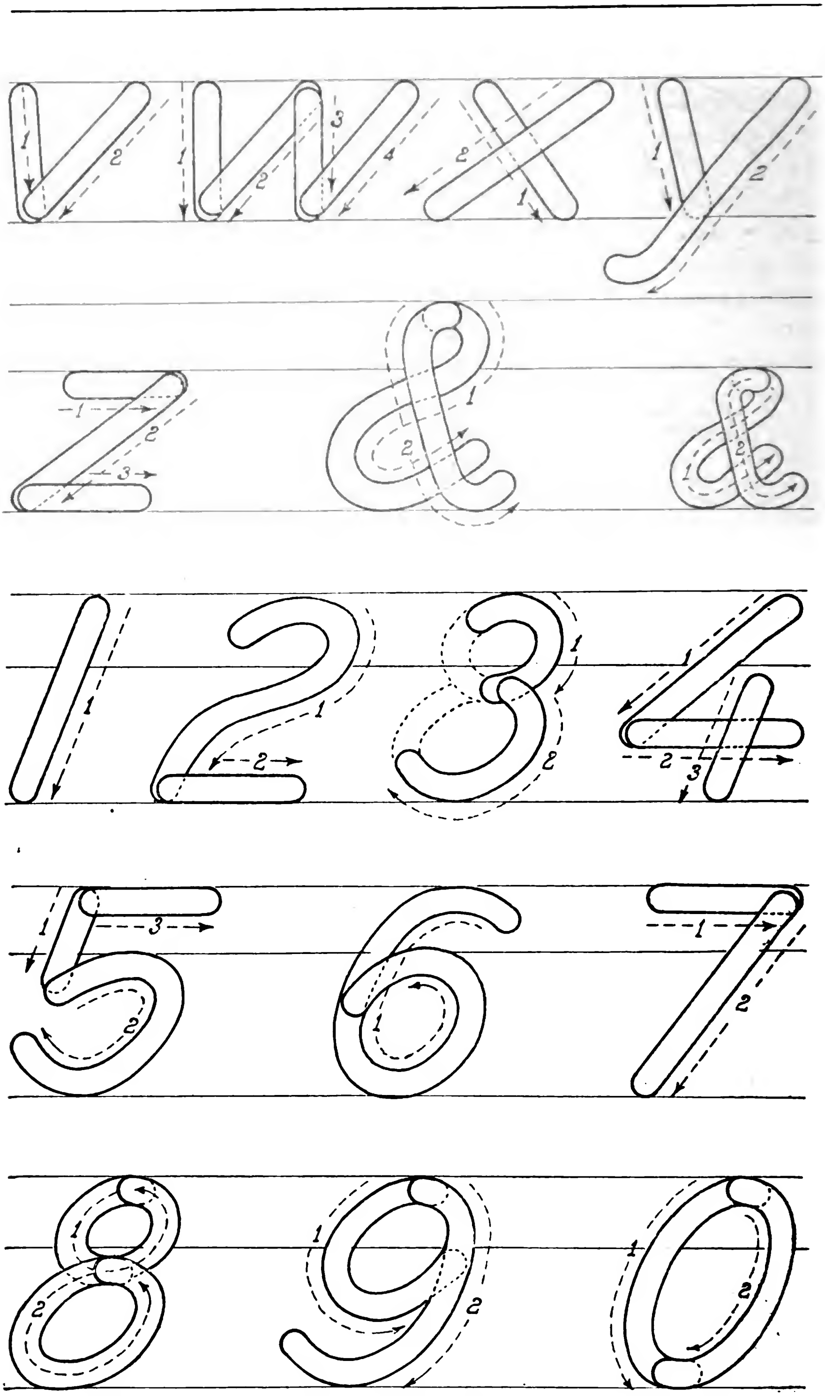


FIGURE 62.—Stroke technique—lower-case slant letters—Continued

ing, and the strokes are made with a steady, even motion. All vertical and slanted strokes are made downward and horizontal strokes from left to right. Lower-case slanted letters are made as indicated in figures 61 and 62. In the "n" and "m" down strokes are made parallel to the slope lines. The arrows show the directions of the strokes, and the numbers show the order in which to make them. In the "v" the first stroke is made almost vertical and the second at an angle of 45° with it. They should not meet before their intersection on the lower guide line. The "w" is made by joining two narrow "v's." The second part of the "r" is made as a simple up stroke with a slight curve at the end. The upper corner of the "h" is made like the upper corners of the "n" and "m." Distinct dots should be placed in prolongation of the "i" and "j." The third stroke of the "k" should begin near the middle of the second stroke and, if extended, should meet the first stroke at the middle guide line. The second stroke of the "x" is made across the first stroke and slightly above its center. The upper part of the "y" is like the "v," the tail being in prolongation of the second stroke and terminating in a slight curve to the left. The down stroke of the "g" is made as long as possible by turning it very short into the lower curve. The "p" and "b" are exactly like the inverted letters "d" and "q."

(2) Single-stroke, capital slant letters are subject to the same rules of slope and direction as the lower-case (small) letters (figs. 63 and 64). The second stroke of the "A" is vertical, and the crossbar of the "A" should be placed at the height of the middle of the small letters. The short middle stroke of the "E" should be slightly above the center of the letter and should not be too short. The two down strokes of the "H" are exactly parallel, and the crossbar should be at the height of the middle bar of the "E." The second stroke of the "K" joins the first slightly below the middle of the first stroke. The third stroke is vertical and begins where the second stroke crosses the middle guide line, and if extended should meet the top of the first stroke. In making the "M" and "N" the parallel strokes are drawn first. The "V," "W," "X," and "Z" are constructed exactly as the corresponding lower-case letters, except that they are made slightly narrower in proportion. The middle (third) stroke of the "Y" is parallel to the slant line, and if extended would go halfway between the tops of the first and second stroke. The horizontal stroke of the "G" should be one-half the total width of the ellipse and should begin slightly above the center of the letter. All numerals are the same height as capitals, except in fractions. The down stroke of the "4" should intersect the horizontal stroke, so that three-fifths of the horizontal is to the left of the down stroke.

FIGURE 68. Stroke technique capital slant letters.

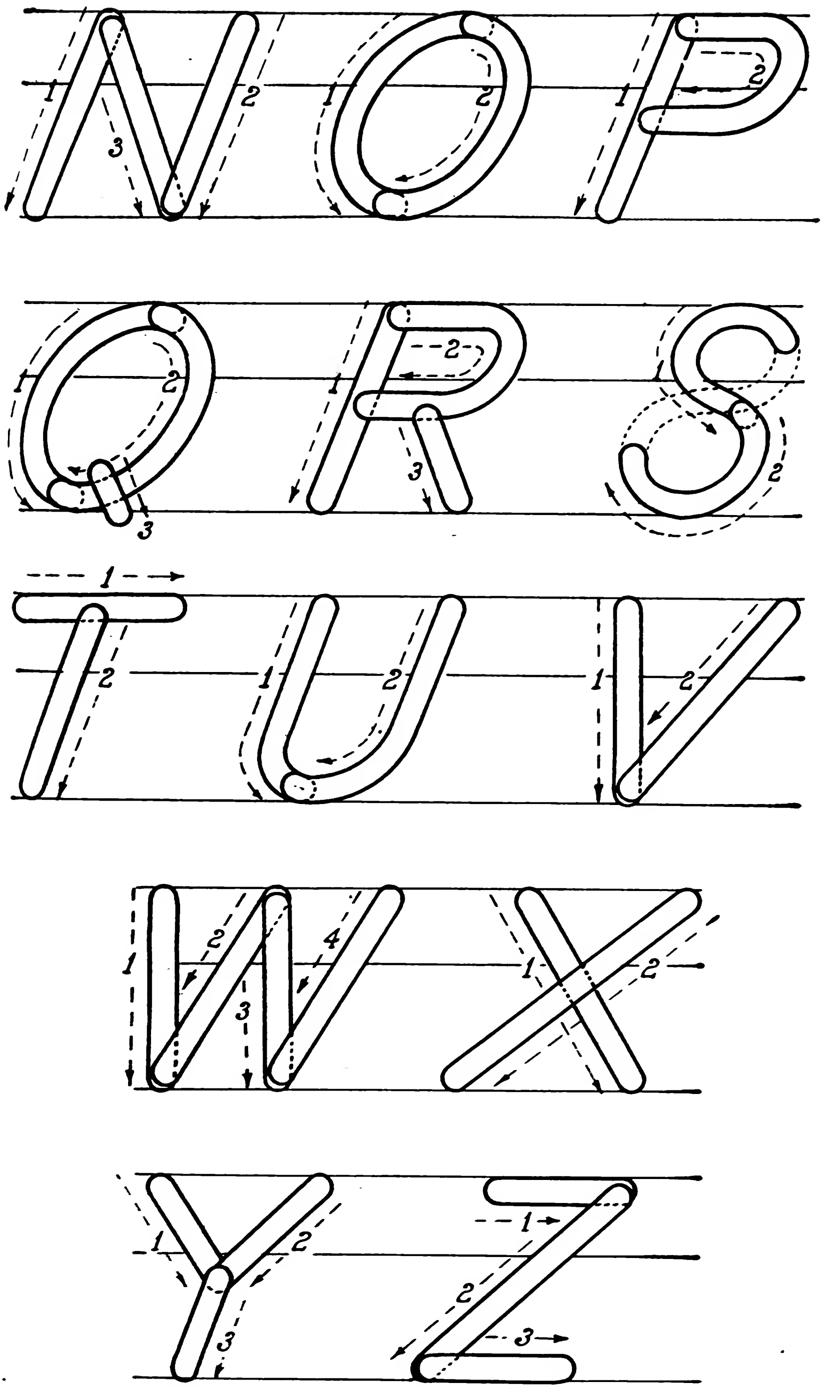


FIGURE 64.—Stroke technique—capital slant letters—Continued

(3) Single-stroke vertical letters, both capitals and lower-case, are made, so far as stroke technique is concerned, exactly as the slanted letters shown in figures 61 to 64, inclusive, except that their down strokes must be strictly vertical and the curved parts must be symmetrical about the center axis of each curve whether such axis is vertical as in the "B," "P," etc., or horizontal as in the "O," "Q," etc.

d. Spacing and alinement.—In order that the beginner may realize the importance of correct spacing he should study figures 65 and 66. These figures show a practical method of correctly spacing letters of the vertical gothic and vertical roman alphabets. This method uses a so-called net value of the printed width of each letter. This net value is determined graphically from the geometrical theory of finding the vertical center line of the plane area of each letter, and then spacing equally the net values of the different letters, as shown in figure 65, in the word "NEW YORK CITY" where the letters "N," "E," and "W" have a width between extreme ends of 6¼, 6, and 10 units, respectively, while their net values are 6¼, 5, and 8 units. A uniform space value of 3 units between the net values of the "N" and "W" and the "E" and "W" in the word "NEW" was selected and the letters spaced accordingly. This method of spacing is not practical if the letters are small, less than ⅜-inch in height; however, a careful study of its principles will develop a sense of artistic and correct letter spacing, an accomplishment required of every good draftsman.

e. Exercise No. 1: drawing slanted capitals.—(1) Capital slanted letters because of their uniform height and the tendency of most persons to slant letters habitually in normal writing should be practiced first. Also, since capitals without lower-case letters may be utilized on some drawings, a beginner may be assigned useful work in an emergency, after studying and practicing capital letters. (For list of exercises in basic and advanced instructions see pars. 107 and 108.)

(2) Secure a form similar to figure 67. With a 3H pencil trace over all letters and words printed on the form beginning at the upper left corner and fill in the vacant spaces between them with letters or words as shown before each vacant space. The student will study the letters in figures 62 (numerals), 63, and 64 while drawing the letters. The following points must be observed:

(*a*) The slant of the letters must be uniform throughout the finished sheet.

(*b*) The space between the drawn letters must equal the space between the printed letters.

LETTERING
CONSTRUCTION AND SPACING

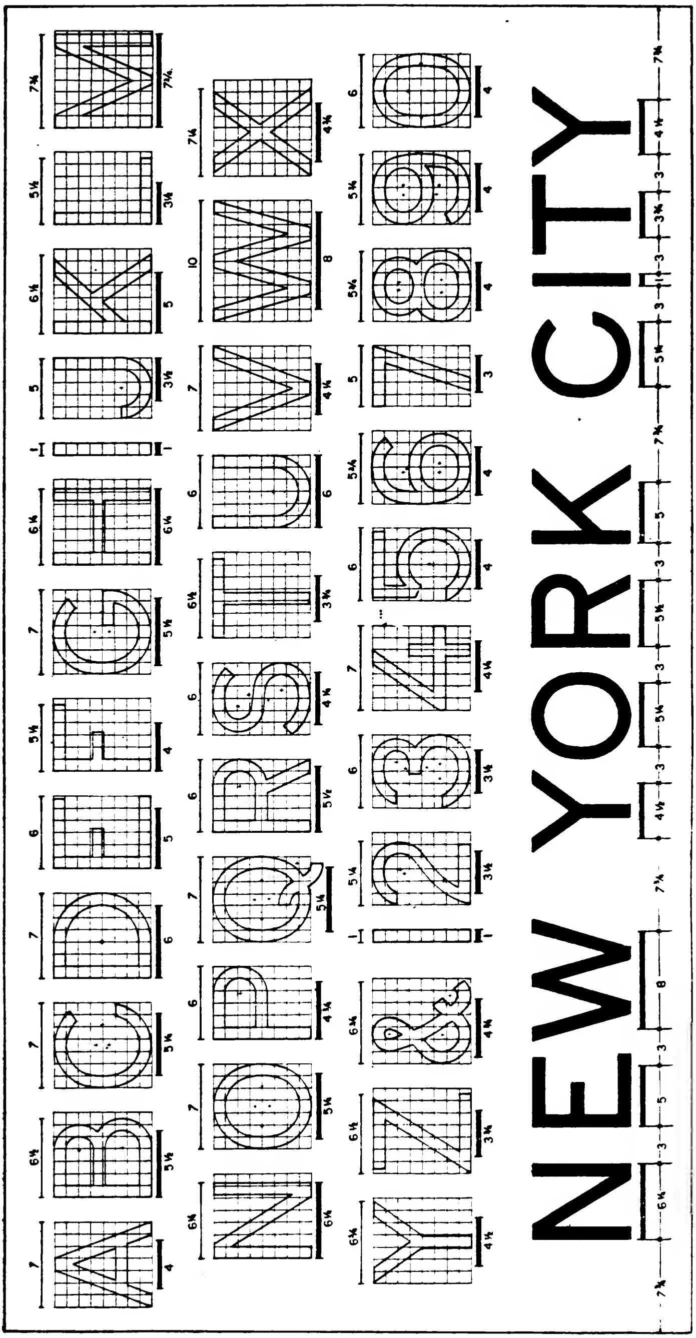


FIGURE 65.—Gothic capitals.

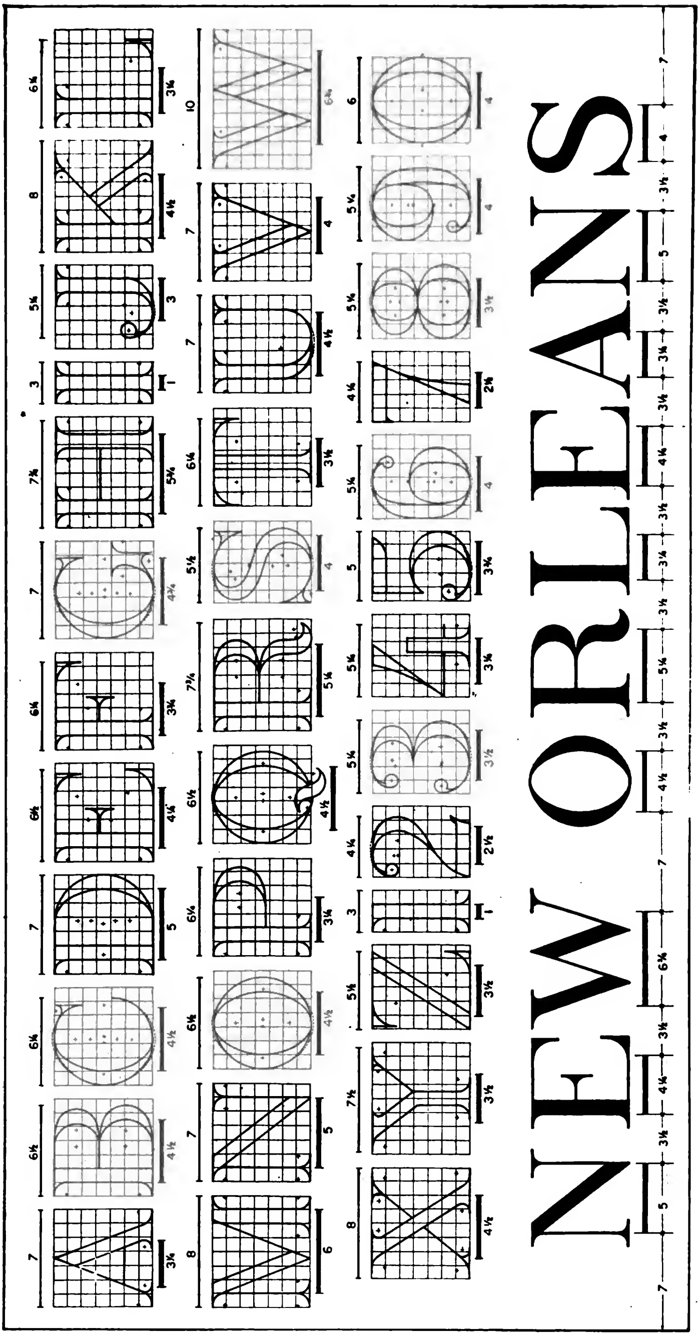


FIGURE 66.—Roman capitals.

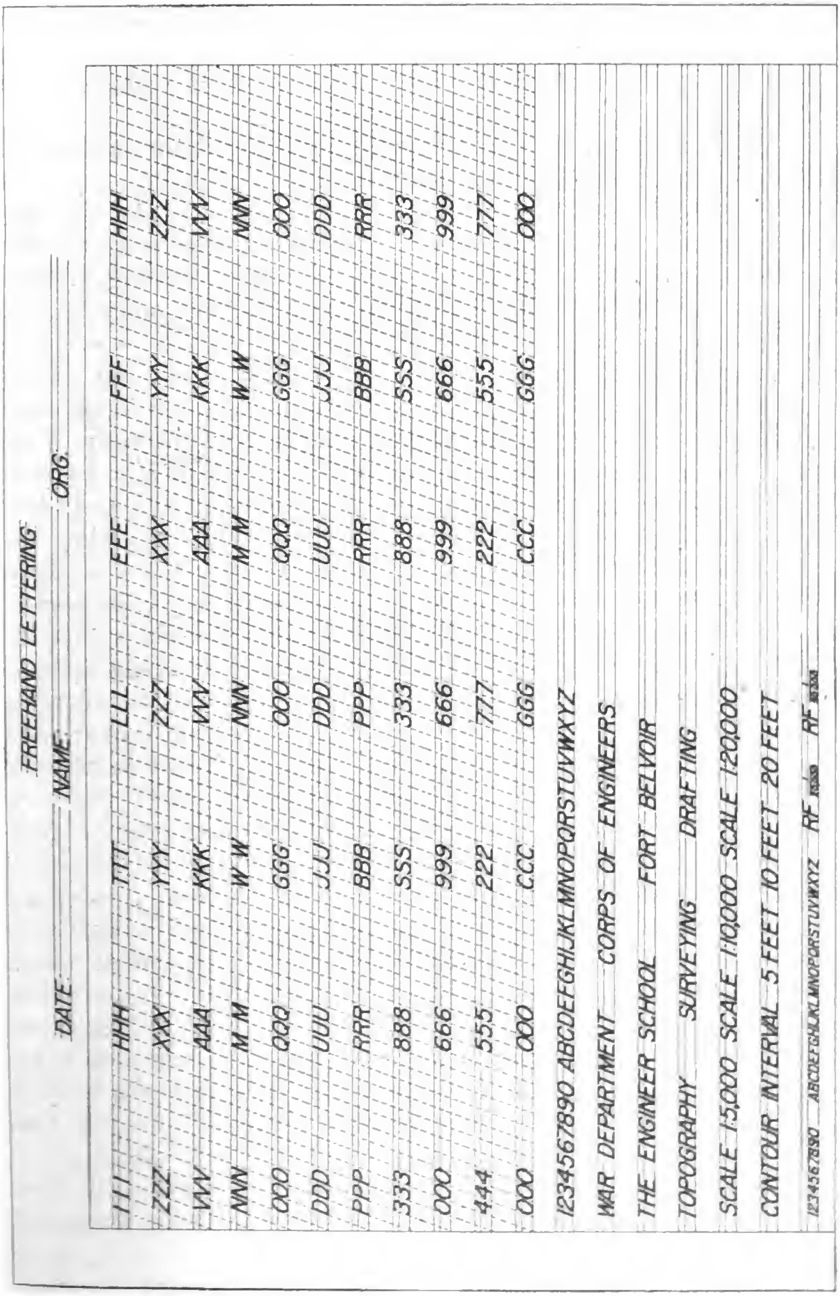


FIGURE 67.—Drawing slanted capitals (exercise No. 1).

(*c*) In drawing the different strokes watch the horizontal and slanted guide lines; draw straight-line strokes always onto the horizontal guide lines, but never beyond.

(*d*) The width and shape of each letter drawn must conform to the width and shape of its printed equivalent.

(*e*) The strokes of the different letters and words throughout the entire sheet must be uniform in thickness.

(3) Avoid the following mistakes: Failing to make the two outside strokes of the "M," "N," and "H" parallel; combining the second and third strokes of the "Y" into one stroke; failing to slant numerals and the "V," "A," "W," "K," and "Z" properly; making the upper part of the "S," "B," "P," "R," "3," and "8" too small; and spreading the lower part of the "K" and "R" too much. Complete the sheet by filling in the blank spaces as indicated in the margin, using the same pencil and style of letters as in the body of the form. With a Payzant lettering pen (No. 7 or 8) or if a Payzant pen is not available, with an ordinary lettering pen, similar to Gillott's 1032, filled with good grade waterproof black drawing ink, go over the lettering outlined with pencil. In connection with the inking of lettering, especially the larger letters, it should be remembered that the thickness of the strokes makes it necessary that the outside of horizontal strokes at top and bottom of letters and the ends of vertical or slanted strokes must be drawn so as to touch the horizontal guide lines exactly. Clean the pen frequently to prevent its clogging, which always causes the different strokes to vary in thickness.

f. Exercise No. 2: drawing slanted lower case.—Secure a form similar to figure 68. With a 3H pencil trace over all letters as printed on the form beginning at the upper left-hand corner, and fill in the vacant spaces between these letters or words with letters and words similar to those placed immediately before each vacant space. Observe the directions given in *e* above. Study the construction of each letter (figs. 61 and 62) while working on this sheet. Complete the sheet by filling in the blank spaces as indicated in the margin, using the same pencil and style of letters as in the body of the form. Ink the lettering and complete the sheet as in the foregoing exercise.

g. Exercise No. 3: drawing vertical capitals.—Securing a form similar to figure 69 and using a 2H pencil, follow the directions of exercise No. 2.

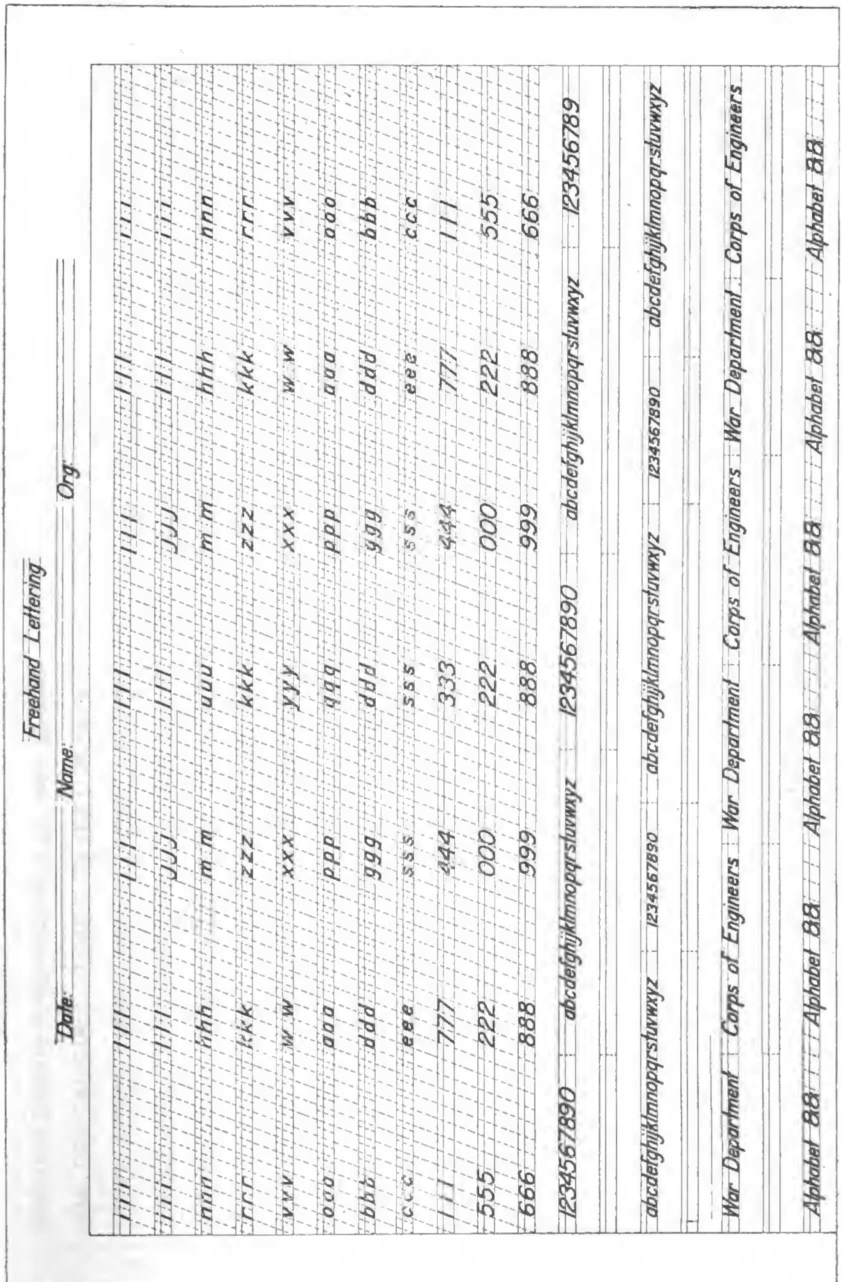


FIGURE 68.—Drawing slanted lower case (exercise No. 2).

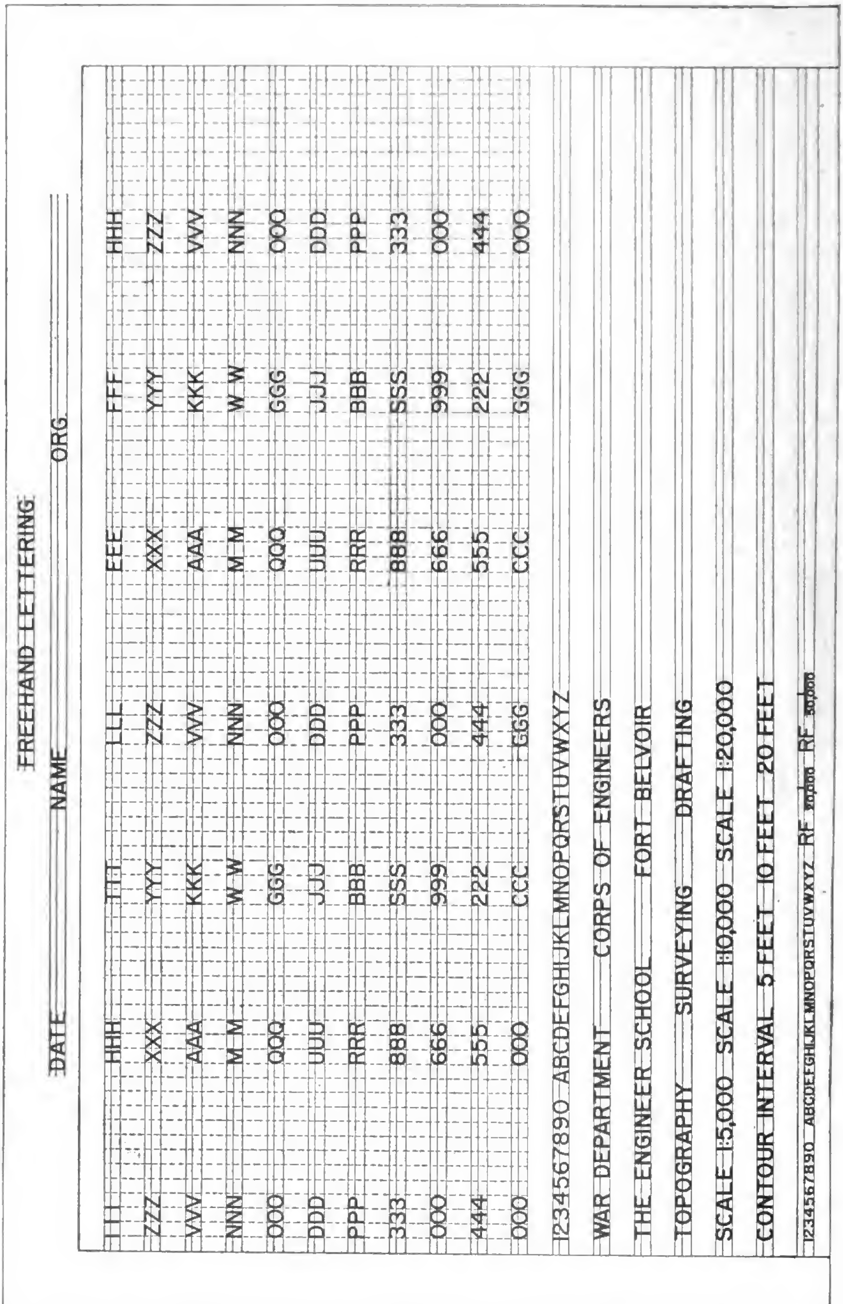


FIGURE 69.—Drawing vertical capitals (exercise No. 3).

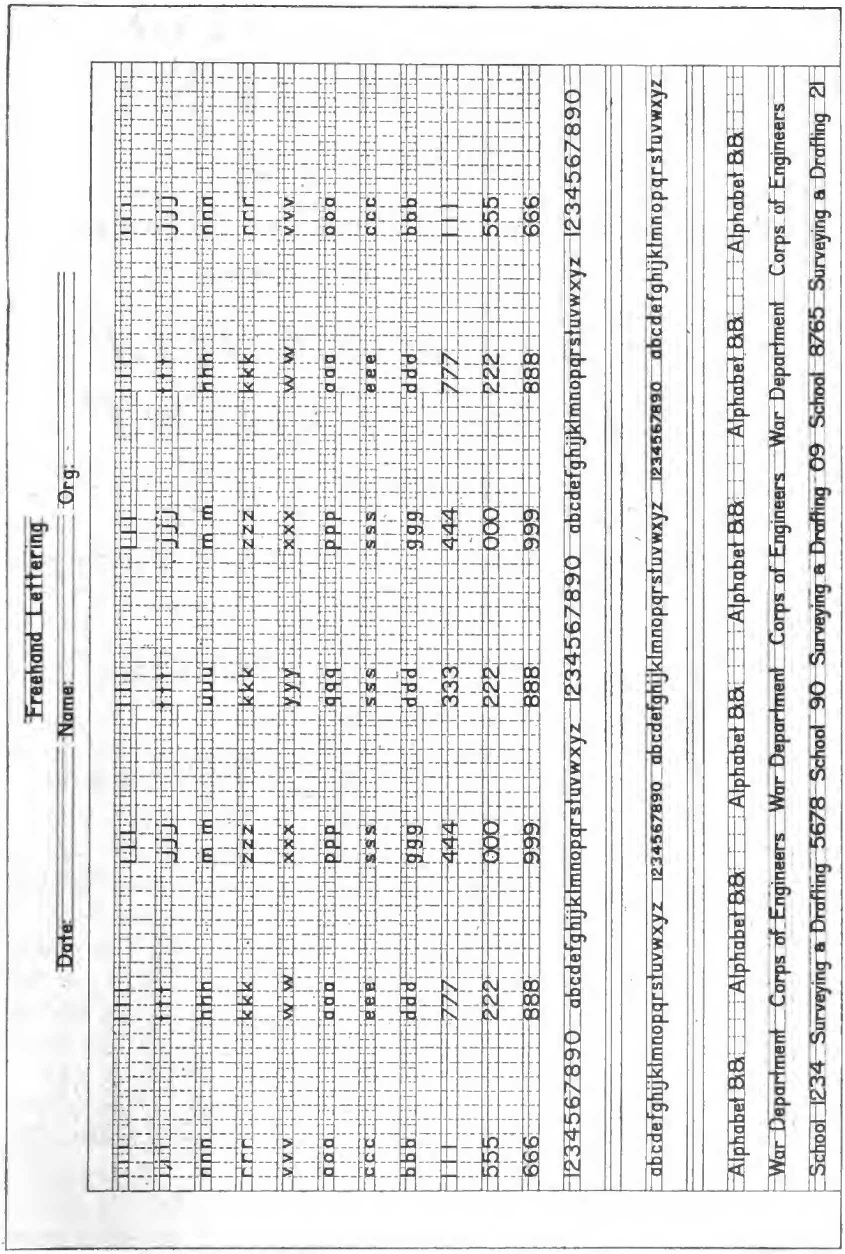


FIGURE 70.—Drawing vertical lower case (exercise No. 4).

TYPES OF MAP LETTERING

Numbers in parenthesis refer to similar numbers in paragraph 21a above

(1)............ABCDEFGHIJ
KLMNOPQRST
UVWXYZ

(2)..... ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz

(3)............*ABCDEFGHIJ*
KLMNOPQRST
UVWXYZ

(4).....*ABCDEFGHIJKLMNOPQRSTUVWXYZ*
abcdefghijklmnopqrstuvwxyzz

(5)...............ABCDEFGHIJKLMNOPQRSTU
VWXYZ

(6)................ ABCDEFGHIJKLMNOPQRSTUVWXYZ
abcdefghijklmnopqrstuvwxyz

(7)....................*ABCDEFGHIJKLMNOPQRSTUVWXYZ*

(8)........................... *1234567890*

(9)................................. *1234567890*

(10)........................... 1234567890

(11)...... ABCDEFGHIJKLMNOPQRSTU
VWXYZ

ABCDEFGHIJKLMNOPQRSTUVWXYZ

a b c d e f g h i j k l m n o p q r s t u v w x y z

1 2 3 4 5 6 7 8 9 0

FIGURE 71.—Types of map lettering (numbers in parentheses refer to similar numbers in par. 21*a*).

h. Exercise No. 4: drawing vertical lower case.—Securing a form similar to figure 70 and using a 3H pencil, follow the directions of exercise No. 2.

21. Map lettering.—*a. General.*—Map lettering includes every style of lettering mentioned in paragraph 20*b* except single-stroke, freehand lettering. Gothic and roman letters, the two basic forms of all letters, are used in various styles on finished maps to designate features of different character, as follows:

(1) Vertical roman capitals for naming civil divisions, such as countries, states, principal cities.

(2) Vertical roman capital initials and vertical lower-case roman for names of towns and villages.

(3) Slanted roman capitals for naming the larger natural water features, such as lakes, rivers, and bays.

(4) Slanted roman capital initials and slanted lower-case roman for names of smaller water features, such as creeks, brooks, springs, small lakes, ponds, marshes, and glaciers.

(5) Vertical gothic capitals for naming the larger natural land features, such as mountains, plateaus, canyons, etc.

(6) Vertical gothic capital initials and vertical lower-case gothic for names of smaller land features, such as peaks, small valleys and canyons, islands, and points.

(7) Slanted gothic capitals for names of railroads, tunnels, ferries, roads, and other public works of importance.

(8) Slanted roman figures for contour numerals.

(9) Slanted gothic figures for elevation numerals.

(10) Vertical gothic figures for bench-mark numerals.

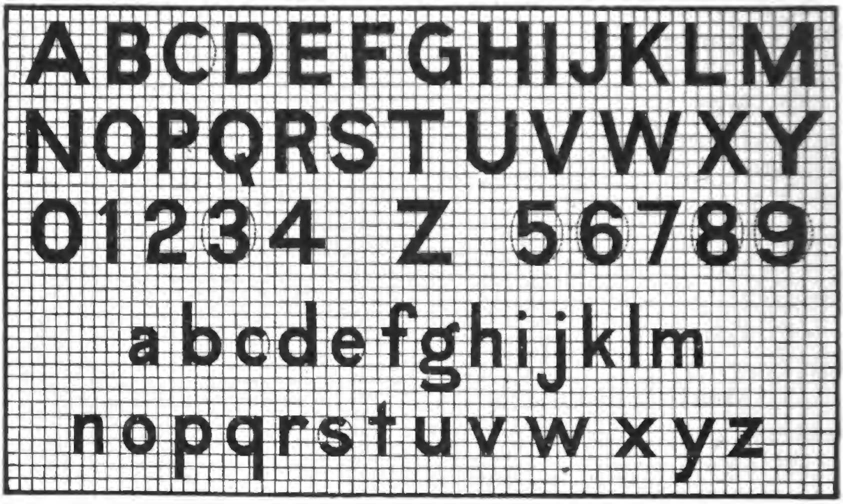
(11) Vertical marginal lettering, all capitals for the more important subjects; capital initials with lower-case letters for all others.

b. Rules.—This lettering is usually set in type and printed on special strips and then attached to the map in its proper place. (See par. 94*d*.) However, every draftsman should know gothic and roman lettering well enough to draw same when necessary. The principal rules for making these letters follow:

(1) *Vertical gothic* (fig. 72①).—(*a*) Make the outlined letter like the upright single-stroke letter, using two strokes instead of one. Thickness of lines of standard letters should approximate one-seventh of the height of capital letters.

(*b*) Cut off the free end of letters such as "C," "G," and "S" perpendicular to the stem.

(*c*) Proportion the width of letters to their height as shown in figure 72.



① Vertical gothic.

② Gothic construction.

FIGURE 72.—Map lettering.

(*d*) Finish letters like "M" and other large letters in making large alphabets by giving them a slight spur as shown in the "M." Observe the details of the letters and follow the order of strokes as shown in figure 72 ②.

(*e*) Allow no ink beyond the pencil line when filling in the penciled outline.

(2) *Slant gothic.*—Make slant gothic lettering exactly as described above, slanting the axis of the letters as in single-stroke slant lettering.

(3) *Vertical roman.*—(*a*) Make the heavy or body strokes from one-sixth to one-eighth the height of the letter and the thin or hair lines comparatively very light (fig. 73).

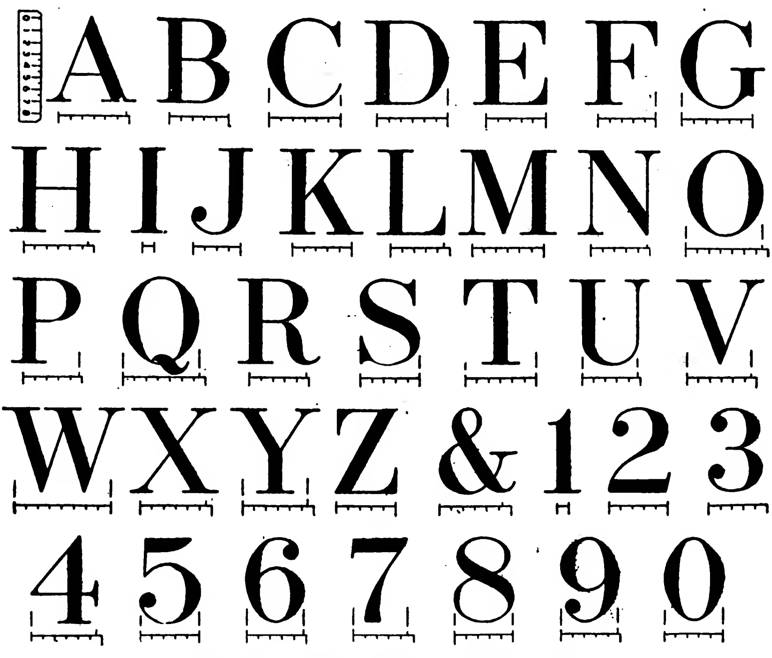


FIGURE 73.—Map lettering—vertical roman.

(*b*) Make the strokes in the order and direction given in the figure and the width of different letters to correspond to the proportion shown.

(*c*) Make the serifs or ends of the strokes (fig. 74) extend one space on each side and join them to the strokes by a small fillet. Omit the body-stroke fillets for letters smaller than 1/4 inch. Make all horizontal strokes light and all vertical strokes heavy except in "M," "N," and "U." Make oblique lines whose lower ends lie to the left, light; those with lower ends to the right, heavy.

(4) *Slant roman.*—Make the letters in the same manner and proportion as the vertical roman, slanting the axis of the letters as in other slanted lettering.

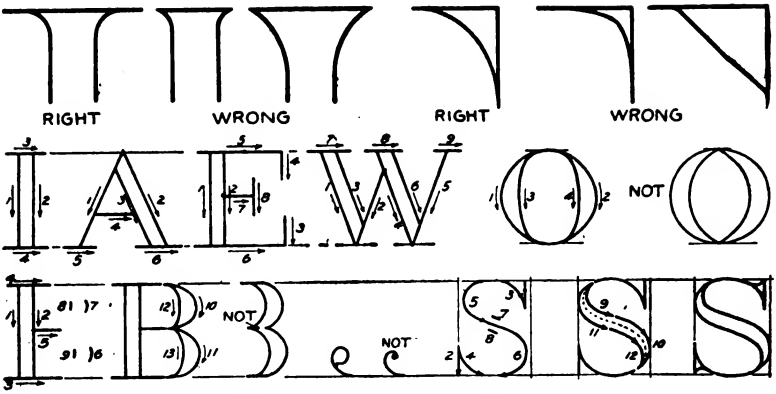


FIGURE 74.—Roman construction.

FIGURE 75.—Slant roman lettering.

c. Exercise No. 5: drawing gothic and roman letters.—Secure a form similar to figure 76. With a 4H pencil trace over all letters and words printed on the form and carefully draw, in the vacant spaces between them, the same letters or words as those immediately preceding each vacant space. Arrange and space the work to conform to the printed matter. With a lettering pen, preferably Gillott's No. 303 for the larger letters and Gillott's No. 170 or 190 or a crow-quill pen for the smaller letters, ink freehand, with uniform strokes of correct width all work on the penciled sheet, including the previously penciled marginal data. Erase pencil lines with art gum.

22. Conventional signs.—*a. General.*—A detailed study of the conventional signs and symbols used on military maps is necessary before attempts are made to draw them. A complete list of conventional signs representing natural and man-made features and military symbols is given in FM 21-30. Figures 82, 83, and 84 show in black the principal symbols. The following rules, if faithfully carried out from the start, will enable even the most inexperienced after little practice to draw neat conventional signs and symbols of uniform appearance:

(1) Study FM 21-30.

(2) On a 1:62,500 map the symbols are drawn the same size as given in FM 21-30. On maps of other scales the signs are drawn relatively larger or smaller.

(3) Make all symbols freehand except those involving rows of straight lines.

(4) Do not crowd too much detail into one group of symbols. Use the correct colors for colored symbols.

(5) Make the symbol for grass freehand. Distribute the tufts over the area so as not to form rows or to give the appearance of regularity in size, and yet so as to have the appearance of uniformity, when viewed as a whole. The bases of these tufts are always parallel to the bottom of the map. Draw the individual sign with five to seven short lines all apparently radiating from a point a little below the base, the tops of the lines forming a curve (fig. 77). Start at the left by making a dot and increase the length of the lines up to the middle one, which is vertical, and then diminish the length of line and end with a dot.

(6) Make the symbol for salt marsh by ruling fine, equally spaced lines parallel to the bottom of the map with occasional grass signs on the lines. Space the lines about $\frac{1}{30}$ inch apart.

(7) Make the fresh marsh or swamp symbol by ruling medium weight short lines across the area parallel to the bottom of the map and draw the grass sign on about half of them.

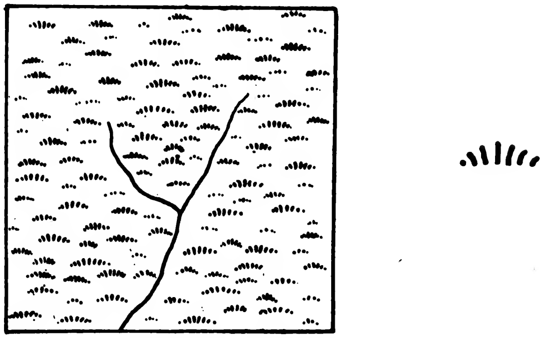


FIGURE 77.—Symbol for grass.

(8) Draw the lines of the symbols for cultivated areas with the straightedge and ruling pen. Draw the lines parallel to one side of the area but not parallel to the bottom of the map. Make the signs on adjoining cultivated fields at an angle with each other, preferably at right angles.

(9) Represent sand by dots evenly distributed over the area (fig. 78). Draw the shore line by a series of heavy dots closely spaced. Then draw a row of lighter dots placed opposite the spaces in the first row. Then draw a third row of still lighter dots spaced the same way. Make

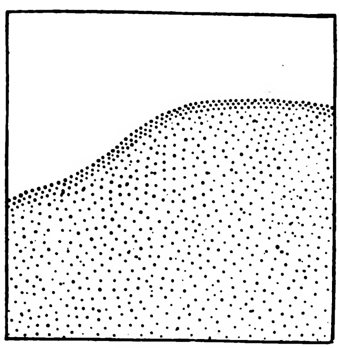


FIGURE 78.—Sand.

the rest of the dots in fan-shaped clusters, spreading them evenly over the area and avoiding a streaky appearance resulting from drawing them in straight lines.

(10) The sign for the broadleaf trees or woods in general is given in figure 79. Make it give the effect of a tree in plan. Scatter these little

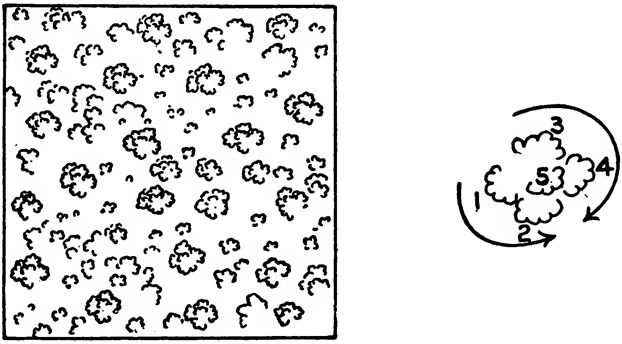


FIGURE 79.—Broadleaf tree symbol.

symbols irregularly over the area if wild growth is to be represented. Represent cultivated growth by placing the symbols in regular rows. (See symbol for orchard in fig. 83.)

(11) Make the sign for pine or narrowleaf tree by drawing five or six short radiating lines of the same weight (fig. 80). Cover the area with varying sizes of this sign and avoid the mistake of placing them in regular rows. First make a group of the largest size signs in

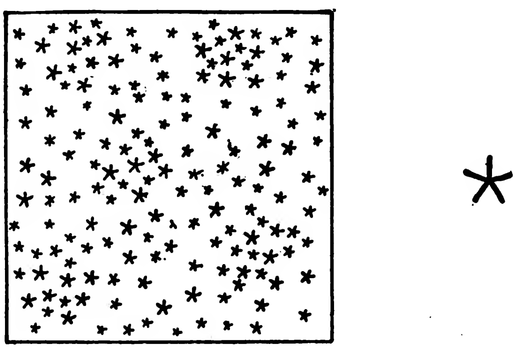


FIGURE 80.—Pine or narrowleaf tree symbol.

different parts of the area, and then fill in the intervening spaces with smaller signs drawn in a lighter stroke.

(12) To execute water lining, draw the first line at a distance from the shore line equal to the width of the line and follow every deviation

exactly (fig. 81). Draw the next line with a slightly greater spacing and at every point the same distance from the first line. Continue increasing the spacing between lines and decreasing the weight of the line very gradually. If there is more than one body of water, draw the lines of the water lining over all the map at the same time, so as to get the spacing and weight of lines uniform. Use blue on a four-color map for streams and water lining.

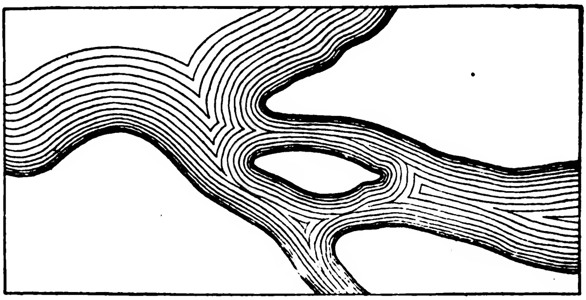


FIGURE 81.—Water lining.

b. Exercise No. 6: works of man.—On a sheet of suitable drawing paper lay off with a 4H pencil the horizontal and vertical lines forming the spaces which contain the different conventional signs and symbols and their designations as given in figure 82. Draw the signs and symbols as shown, using T-square and triangles as far as possible. Draw guide lines for all lettering and insert the names, etc., of the different signs. Observe the following:

(1) Make symbols and letters so that their size is in direct proportion to those shown in figure 82; use lightly drawn guide lines where necessary.

(2) Draw dots and dashes of equal length, uniformly spaced.

(3) Make cross ties on railroads as short as possible, always perpendicular to the right-of-way.

(4) Corners of buildings must be drawn clear and sharp; buildings must be rectangular.

(5) Symbols for telegraph lines must be made as small as possible and uniformly spaced.

(6) Make lettering uniform in height and slant.

(7) Make all cross hatching even and uniform.

(8) Draw all signs and lettering, including marginal data, in position corresponding to that shown in figure 82.

(9) Ink the symbols and all lettering (in black), using lettering pens of proper size.

(10) Clean the sheet by erasing pencil lines and smudges with art gum.

c. Exercise No. 7: natural features, including cultivation.—On a sheet of suitable drawing paper lay off with a 4H pencil the horizontal and vertical lines forming the spaces which contain the different conventional signs and symbols and their designations as given in figure 83. Draw all signs and symbols and all lettering as explained in the preceding exercise, and observe in addition to the directions given above the following:

(1) Accentuate every fifth (even 100-foot) contour.

(2) Arrange the dots in sand dunes and salt ponds in an irregular fan-shaped pattern as shown.

(3) Draw hachure lines in cuts and fills perpendicular to sides of road and far enough apart so they will not run together, their ends never touching the road symbol.

(4) Study the symbols representing bluffs, especially the one for rocky bluffs, before drawing them.

(5) Analyze the symbols for woods, orchards, etc., and draw them as shown.

(6) Space parallel lines in the different symbols for marsh and the symbol for tidal flats equidistant from each other; note that these lines are not continuous.

(7) Study the vertical parallel alinement of the staggered, horizontal dashed lines for mud, and space them uniformly.

(8) The hachure marks on depression contours must be short and must not touch each other; at the point of contact they must always be perpendicular to the tangent of the contour.

(9) Letter, using guide lines and designating the various symbols.

(10) Ink the symbols and all lettering, in black, using lettering pens of proper size.

(11) If preferred, the symbols may be made with colored ink, colors to correspond to those shown in FM 21-30.

(12) Clean the sheet by erasing pencil lines and smudges with art gum.

d. Exercise No. 8: special military features.—(1) Figure 84 shows some of the principal symbols representing purely military features with which the average military draftsman should be familiar. These symbols are shown in black only. If it is desired to show them in color those representing friendly troops or installations are shown in blue, and those of the enemy in red. The only exceptions are as follows:

(*a*) Symbols for areas to be covered by friendly fire, though always located in enemy territory, are executed in blue.

(*b*) Symbols for gassed areas, wherever located, are always executed in red.

(2) On a sheet of suitable drawing paper lay off with a 4H pencil the spaces which contain the different signs and symbols and their designations as shown in figure 84. Draw the signs and symbols using T-square, triangles, and compass as far as practicable. Draw guide lines for all lettering and insert names, numbers, etc., as shown in the figure. Observe the rules for making these symbols as given in FM 21-30. Letter all marginal data. Ink all work on the sheet using black ink only. Clean the sheet by erasing pencil lines, etc., with art gum.

23. Miscellaneous drawings.—*a. General.*—The drafting exercises in *b* and *c* below consist of the making of two drawings as shown in figures 85 and 86. These drawings are to be made with T-square, triangles, scales, compass, and any other instrument that will tend to facilitate a precise and rapid execution of the work.

b. Exercise No. 9: grid lines and scale.—On a sheet of suitable drawing paper lay off with a 6H pencil the horizontal and vertical border lines forming the space which contains the problems in figure 85. For each problem draw the guiding line or lines, from which the problem progresses, in the same corresponding positions as shown in the figure. Proceed with the construction of the problems as follows:

(1) *Constructing grid lines.*—Using scaled dimensions from figure 85, draw the line *AB* and mark the point *O*. With a compass draw small arcs cutting the line *A* at *B* equidistant from *O*. From *A* and *B* draw intersecting arcs at *C* and *D*, respectively, and connect the two intersections by a fine line which will be perpendicular to *AB*. With dividers properly set mark from *O* in the four directions toward *A*, *B*, *C*, and *D* all necessary points at which both horizontal and vertical lines are to cross the lines *AB* and *CD*. From the last mark, made with the dividers, at the end of each series (at *A*, *B*, *C*, and *D*) lay off, parallel to *AB* and *CD*, respectively, using the same setting of the dividers, the necessary number of points to establish the required number of grid lines. After drawing the grid lines draw the two diagonals connecting the four corners of the grid system. As this construction has the same number of squares in both directions, these diagonals, used as a check to test the accuracy of the drawing, should cut the squares through which they pass at their very corners. Further test the accuracy of the drawing by the length of the diagonals of different series of squares as indicated in figure 85. The finished (inked) drawing should show the grid lines only.

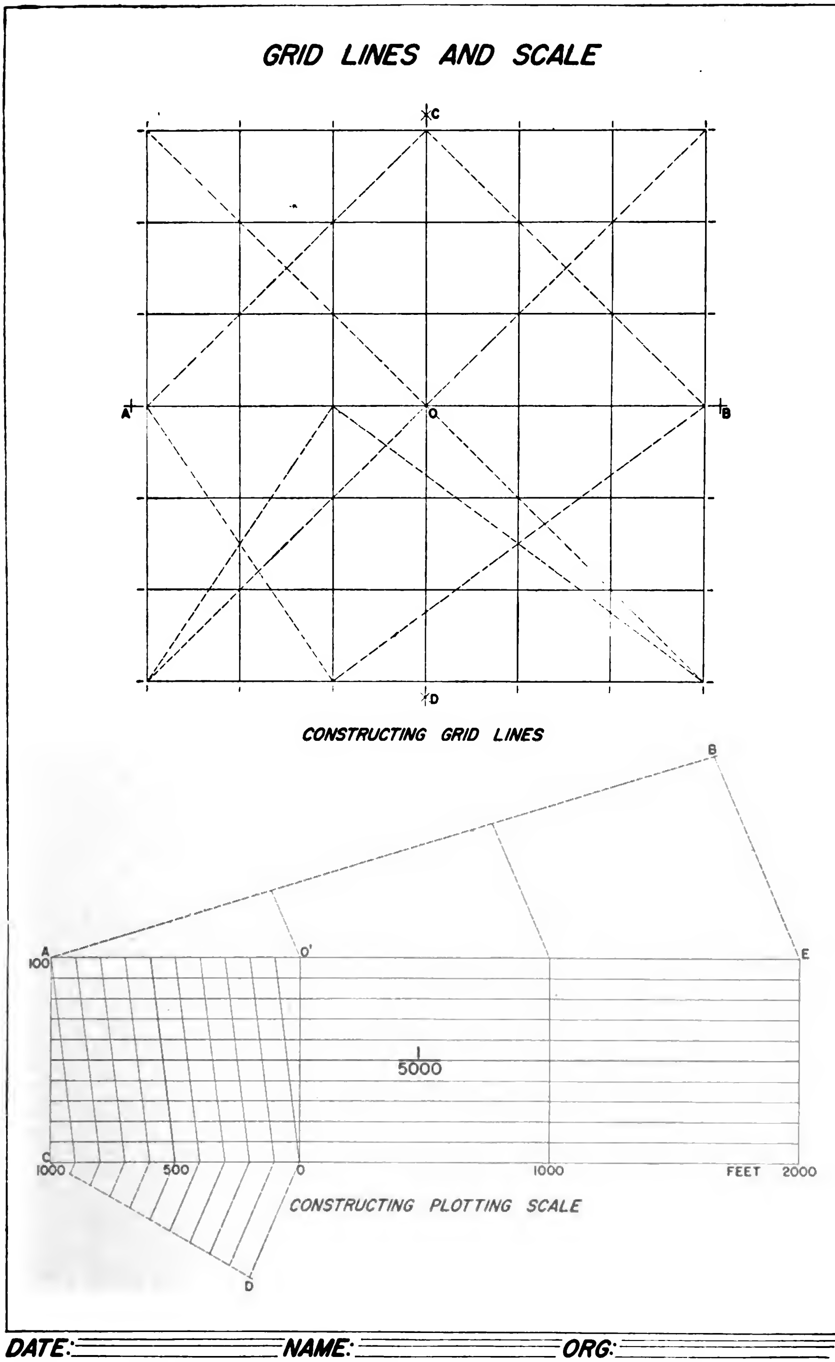


FIGURE 85.—Constructing grid lines and scale (exercise No. 9).

(2) *Constructing plotting scale.*—The problem is to construct a plotting scale of 1:5,000 denoting two full 1,000-foot units and one subdivided 1,000-foot unit as shown in figure 85. Draw the line AE after calculating its exact length—

$$AE = \frac{3{,}000 \times 12}{5{,}000} = 7.2 \text{ inches.}$$

Draw ten lines all parallel and equidistant to AE 0.2 inch apart. Divide the line AE into three equal parts, each part to represent 1,000 feet, by drawing a line similar to AB, laying off any convenient length three times along this line. Connect the last point with E by drawing a fine line. Draw two more fine lines, parallel to the last one, from the other two points on AB cutting the line AE. From the two cutting points on AE thus obtained, and from the points A and E, draw perpendiculars to AE connecting the ten parallel lines previously drawn, labeling the lower ends of these perpendiculars 1,000, 0, 1,000, and 2,000, respectively. Divide $C0$ into ten equal parts, using the same method by which AE was divided into three equal parts. (Note line CD, etc., fig. 85.) Carry the ten divisions as obtained for $C0$ to the corresponding parts of the line AO'. Connect diagonally each division point on AO' with the preceding division point on $C0$ as shown in figure 85. The finished inked scale should show only the solid lines and numerals indicated in the figure. Letter your drawing when you have completed the line work. The sheet may be inked if desired.

c. Exercise No. 10: topographic diagrams.—On a sheet of suitable drawing paper draw with a 6H pencil the diagrams and scales of figure 86, organizing your work as in the figure. These diagrams, etc., are representative of principles frequently applied in topographical drafting and like the problems in the preceding exercise are to be made with the aid of any available drawing instrument. Proceed with the construction as follows:

(1) *Problem A—to reduce the figure of an irregular area without a pantograph.*—Locate the plot of the area to be reduced, its size and shape being given or known, in a convenient position as shown. From any point A, preferably outside the given area, draw lines to every corner of the irregular area as A–1, A–2, A–3, etc., and connect two widely separated points in the original area by a line (2–9) nearly perpendicular to a line from A to the approximate center of the figure. Calculate the dimensional ratio between the scale of the original plot and the scale of the reduced plot. Assuming the original plot scale as being 1:20,000 and the reduced plot scale to be 1:62,500, this ratio would be equal to 20,000 divided by 62,500 or 0.32. Divide

the distance AC into two parts, AC' and $C'C$, making the part AC' equal to the calculated dimensional ratio (0.32) of the line AC. Through the point C' draw a line parallel to 2–9. Where this line intersects the lines A–2 and A–9, mark 2′ and 9′, respectively. Beginning at 2′ draw successive lines parallel to 2–3, 3–4, 4–5, etc., using their intersections with lines A–3, A–4, A–5, etc., as the terminus of each line to be drawn. Label the new points 3′, 4′, 5′, etc.

(2) *Problem B—to construct a plotting scale 1:40,000 to read to 10,000 yards.*—Draw parallel horizontal lines as in figure 86. As the scale is to read a maximum of 10,000 yards, the length of the lines will be:

$$\frac{10{,}000 \times 36}{40{,}000} = 9.0 \text{ inches.}$$

Divide their lengths into exactly ten 1,000-yard parts by the vertical lines as shown. Subdivide the left rectangle at top and bottom into ten equal parts and connect the divisions with parallel diagonal lines as shown. Draw numerals on the scale as indicated in the figure.

(3) *Problem C—to construct a conversion scale (1:20,000) showing relative values for miles, yards, feet, meters, and kilometers to read 6,000 yards.*—(*a*) Draw five parallel lines as in the figure. After finding that 6,000 yards at the scale of 1:20,000 equals $\frac{6000 \times 36}{20{,}000} = 10.8$ inches, lay off 10.8 inches on the scale which is to represent the measurements in yards. Divide this distance into six 1,000-yard parts and each 1,000-yard part into ten 100-yard parts. By utilizing the yard scale, divide the line representing measurements in feet into eighteen 1,000-foot divisions and each of the latter into ten 100-foot parts.

(*b*) On the mile scale, mark opposite 1,760 yards and each multiple thereof as many miles as are shown in the figure. Divide each mile into four parts, ¼, ½, and ¾, and label accordingly. On the meter scale, adjoining the foot scale, mark every 1,000-meter mark, first opposite 3,280.0 feet and then each multiple of the latter. Divide each 1,000 meters into ten 100-meter units. On the kilometer scale mark every kilometer opposite each 1,000-meter mark of the meter scale and subdivide each kilometer into ¼, ½, and ¾ parts by utilizing the 250, 500, 750, etc., meter mark on the meter scale. Add all lettering, numerals, and marginal data. Ink the sheet and erase pencil lines and smudges with art gum.

24. Map drawing and tracing.—*a. General.*—(1) Map drawing and map tracing are the final steps in the production of originals

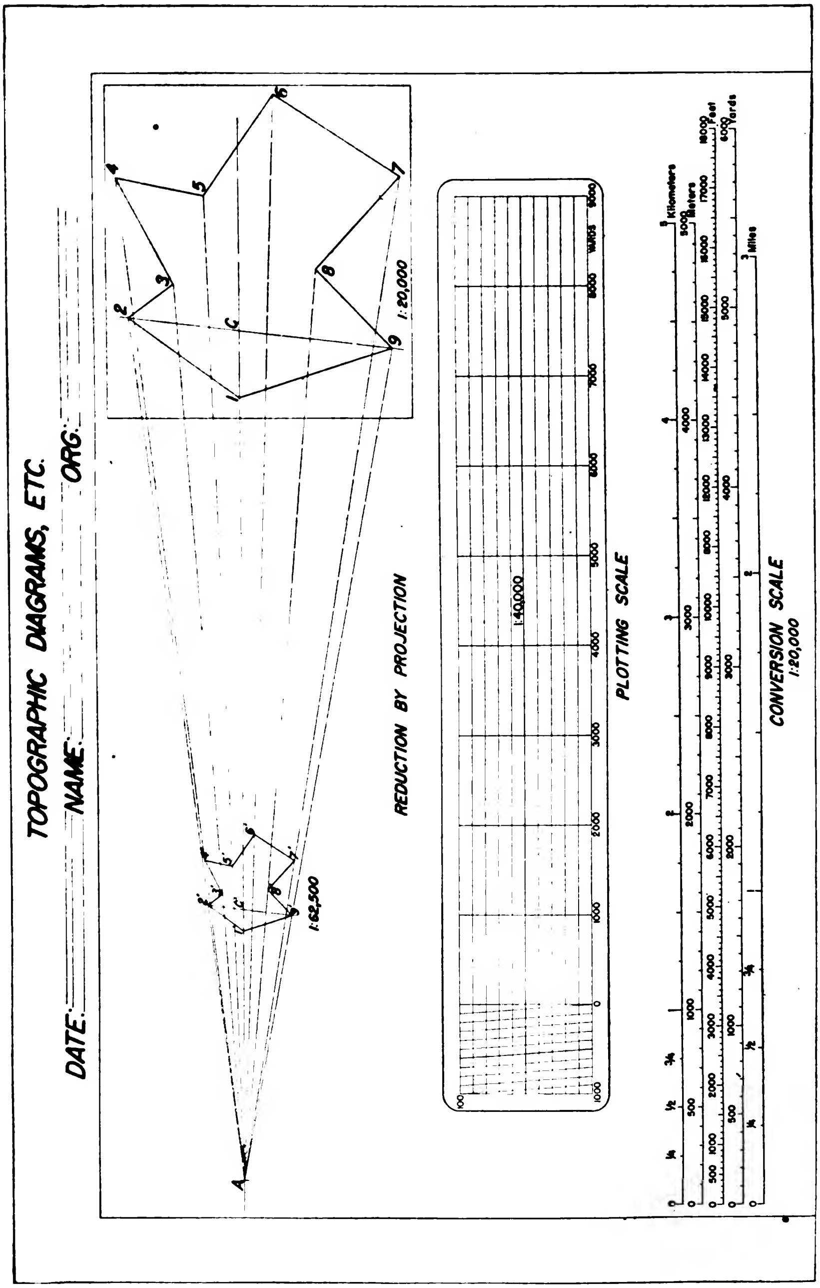


FIGURE 86.—Constructing topographic diagrams (exercise No. 10).

from which any number of copies may be reproduced by one of the following methods:

(*a*) Direct lithographic process, for which transparent originals (mostly tracings) are used.

(*b*) Photo-lithographic process, for which either drawings or tracings can be used.

(*c*) Photographic process, for which drawings or tracings may be used.

(*d*) Semiphotographic processes (such as blueprints, Van Dyke prints, B and W prints, etc.), for which tracings or other transparent positives are used.

(2) From this it can be seen that the type of reproduction equipment available governs whether drawings or tracings should be made. In preparing drawings or tracings for reproduction, great care must be taken to get all the lines solid black. If very fine lines are used they will still reproduce at considerable reduction provided each is formed by a solid ridge of black ink. Do not use yellowish paper for reproduction work. Pure white paper gives the best results.

(3) Lettering on drawings and maps intended for reduction should be of more open character than for ordinary work. Exaggerate somewhat the width of ovals or small loops, such as in "e," to guard against the filling of those parts in reduction. Letters should not be reduced to less than $\frac{1}{32}$ inch. Marginal data must be complete and conform to the directions in *c* below (fig. 88) and in paragraph 48*a*.

(4) Any irregularities on a drawing may be corrected by painting out with white opaque water color or covering with white paper and pasting. If necessary a view may be cut out and pasted in a different position without detriment to the work of the photographer or lithographer.

(5) For reproductions in several colors, such as a four-color map, a drawing must be made for each color desired. In order to obtain a perfect registry of colors on the finished reproductions, the map is first drawn all in black, and is then reproduced in light blue lines by photography on sensitized metal-mounted drawing paper or by photo-lithography on smooth, heavy, white paper or bristol board with all lines printed light blue so that they will not photograph. Drawings are then made on these copies, one for each color, i. e., one on which all features to be shown in brown are gone over with black ink, one on which all features to be shown in green are gone over with black ink, one on which all features to be shown in blue are gone over with black ink, one of which all features to be shown in black are inked black, etc.

(6) For reproductions in several colors, such as overlay prints, where absolute register of colors is not important, a tracing for each color is made. In preparing for such work the cloth for the several tracings should be cut from the same roll with the grain running in the same direction. (See par. 11*c*.) Draw matching marks in the form of L's at the four corners of each drawing, being careful that they coincide. It is particularly important that tracings for different colors be transferred by the lithographer before the tracing cloth has had time to expand.

b. Exercise No. 11: contour and road pen practice.—On a sheet of tracing cloth of suitable size, prepared by rubbing with powdered chalk, trace on the dull side of the cloth the map shown in figure 87, using black waterproof drawing ink. Proceed with the work in the following order:

(1) Trace the outline or border and all lettering, including contour numbers and marginal lettering. Draw guide lines with a soft (B) pencil for all lettering and numbers.

(2) Trace all roads (irregular roads with road pen), buildings, and other works of men, and all natural water features, including intermittent streams.

(3) Trace with the contour pen all accentuated contours and then all intermediate contours.

(4) Finally, trace symbols for wooded areas.

(5) Clean pencil lines, etc., off tracing with a clean, soft cloth moistened with gasoline; this will not affect the ink lines.

c. Exercise No. 12: map tracing.—On the dull side of a sheet of tracing cloth, prepared by rubbing with pounce or powdered chalk, trace in ink the complete map shown in figure 88, omitting encircled numbers and arrows. Proceed with the work in the following order:

(1) Trace with lines of proper thickness the borderline and all other straight-line work.

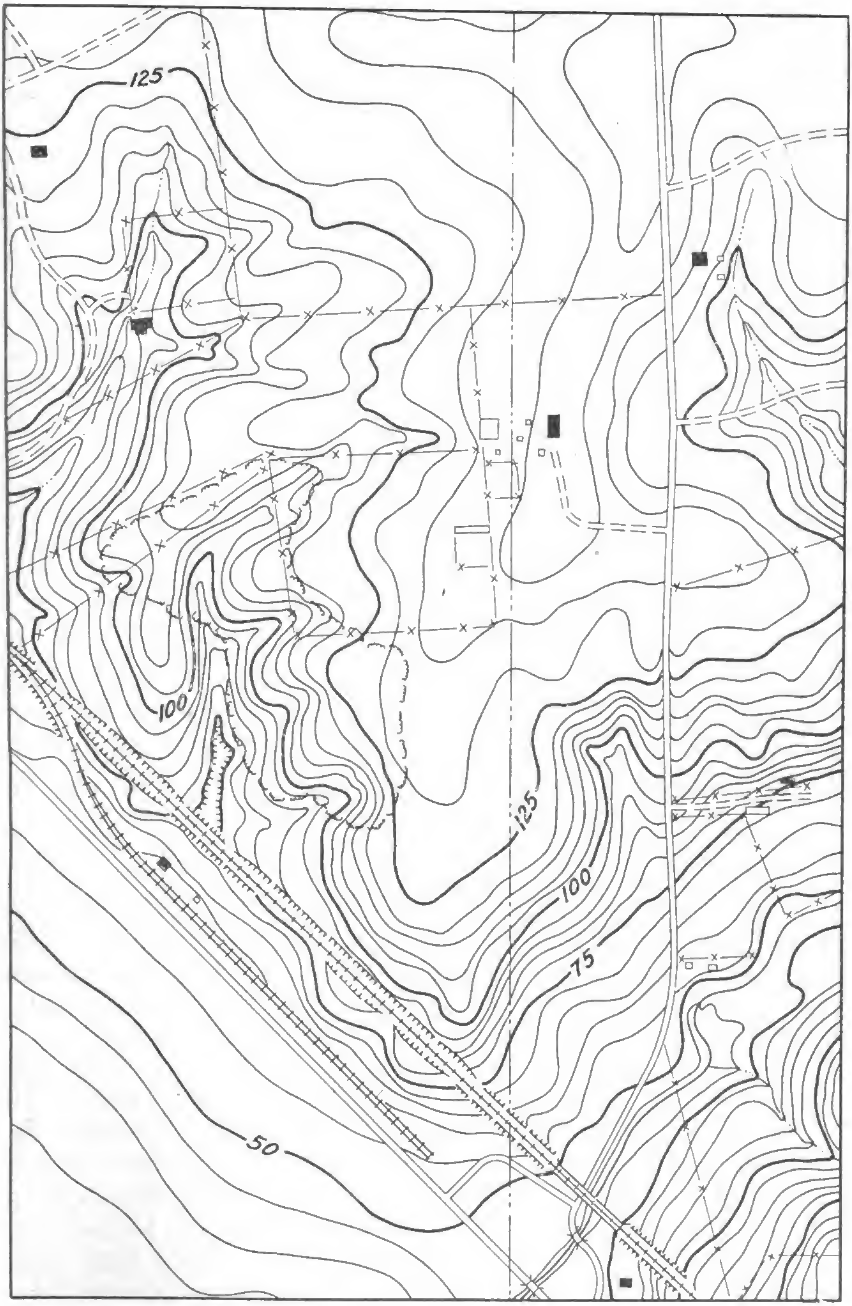
(2) With a B pencil draw fine guide lines for all lettering.

(3) Trace with a lettering pen similar to Gillott's No. 303 all lettering except contour numbers and smaller letters which are traced with a Gillott No. 170 or a crow-quill pen; use the guide lines previously drawn.

(4) Trace all roads and railroads, drawing their irregular curves first with the ruling pen, the railroad pen, or the road pen.

(5) Trace all other man-made structures, using the ruling pen wherever possible.

(6) With a Gillott No. 303 or finer pen, trace all water features.



NOTE.—Although here shown in black, this exercise sheet should actually be printed in a light tan color for inking by students.

FIGURE 87.—Contour and road pen practice (exercise No. 11).

(7) With a contour pen, trace first all accentuated contours, then all intermediate contours. If the interval between two accentuated contours in 0.2 inch or less, the crow-quill pen may be used to trace intermediate contours.

(8) Trace all wooded regions, etc., using either a Gillott No. 303 or finer pen. If necessary, draw guide lines for larger orchards, thus insuring uniformity for tree spaces and rows.

(9) Complete the tracing by inserting all marginal data.

(10) Clean the tracing and remove the pencil guide lines by rubbing gently with a piece of soft cloth dipped in gasoline.

d. Exercise No. 13: map drawing (colored).—Transfer the complete map shown in figure 89 (4-color map) on to smooth-surfaced white drawing paper to an enlarged scale by the graphical method. employing squares as described in paragraph 93*b*, using a fine pointed 2H pencil. Ink the different features in the same order as directed in *c* above. Draw guide lines for all lettering with a fine pointed B pencil. Use waterproof drawing inks (color as indicated below) for steps referred to in *c* above:

(1) *Black.*—For steps (1), (3), except contour numbers, (4), (5). and (9).

(2) *Blue.*—For step (6). Use water lining where appropriate.

(3) *Brown.*—For step (7) and all contour numbers.

(4) *Green.*—For step (8), substituting woodland symbol. Finish the map by cleaning it with art gum.

Section V

AERIAL PHOTOGRAPHS

25. General.—Attempts to utilize photographs in connection with map making were made soon after the invention of photography. By 1860, surveying with photographs taken from ground stations had been placed on a scientific basis. During the World War, after a gradual improvement in equipment and methods, aerial photography became an important factor in the preparation of military maps. The Air Corps is charged with performing aerial photographic work for military mapping operations in accordance with specifications prepared by the Corps of Engineers. Constant improvements in equip-

ment, better methods resulting therefrom, and special training of photographic units enable the Air Corps to meet efficiently all demands for aerial photographs. Close cooperation between the Air Corps and the Corps of Engineers is necessary, since the engineers have the duty of supplying the Army with maps.

26. Uses and limitations.—*a.* An aerial photograph is a perspective picture, with either a vertical or an oblique viewpoint, taken from any kind of aircraft. Except for color values the aerial photograph conveys the same impression in image as received by the human eye from the same viewpoint.

b. The vertical aerial photograph (par. 27) is a valuable instrument for conveying topographic information for the following reasons:

(1) It possesses in pictorial effect a wealth of detail which no map can equal.

(2) It possesses accuracy of form.

(3) With freedom of flight, an aerial photograph may be prepared in a short time.

(4) It may be reproduced in quantity by lithography.

(5) It may be made of an area otherwise inaccessible because of either physical or military reasons.

c. The vertical photograph is inferior to a map in respect to the following features:

(1) Important military features which are emphasized on a map are sometimes obscured or hidden by other detail.

(2) Neither absolute position nor absolute elevation can be obtained.

(3) Relative relief is not readily apparent.

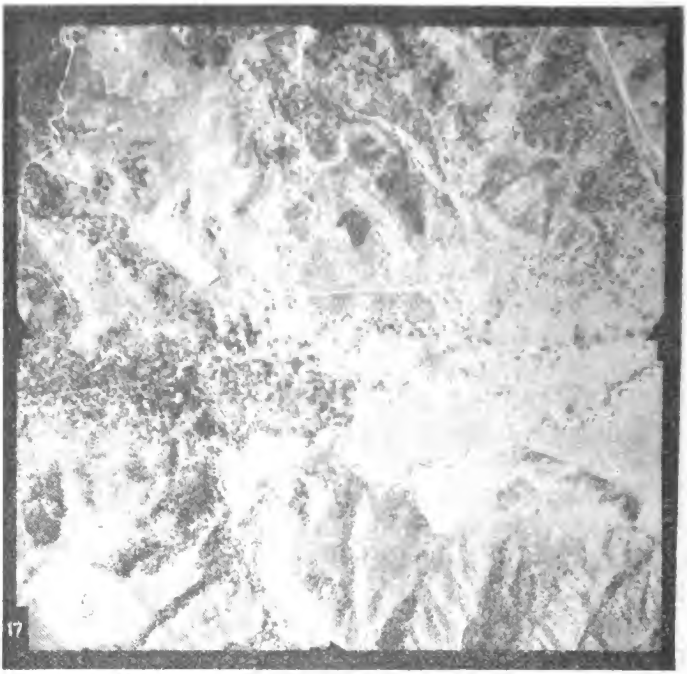
(4) Displacements of position caused by relief and camera tilt usually do not permit the accurate determination of either distance or direction.

(5) Because of a lack of contrast in tone, it is difficult to read in poor light.

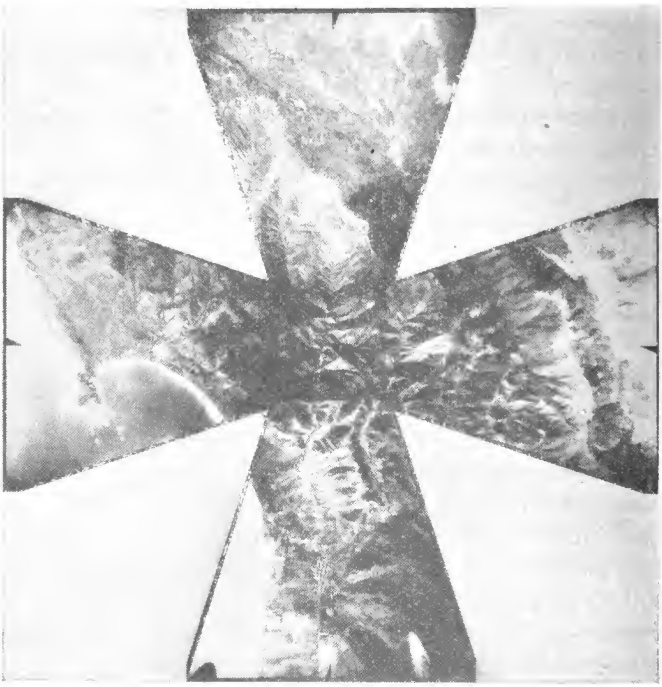
(6) Marginal data furnished on maps are generally lacking.

d. Aerial photographs may be utilized in extending horizontal and vertical control in order to reduce the field work of survey parties to a minimum. Relief and tilt distortions (pars. 71 and 72) in photos are adjusted and contours are drawn in the drafting room to produce maps from aerial photos.

27. Types.—*a. Verticals* (figs. 90 ① and 91 ①).—The usual type of photograph for military purposes is the vertical; it is taken with a single-lens camera with the optical axis at the moment of exposure

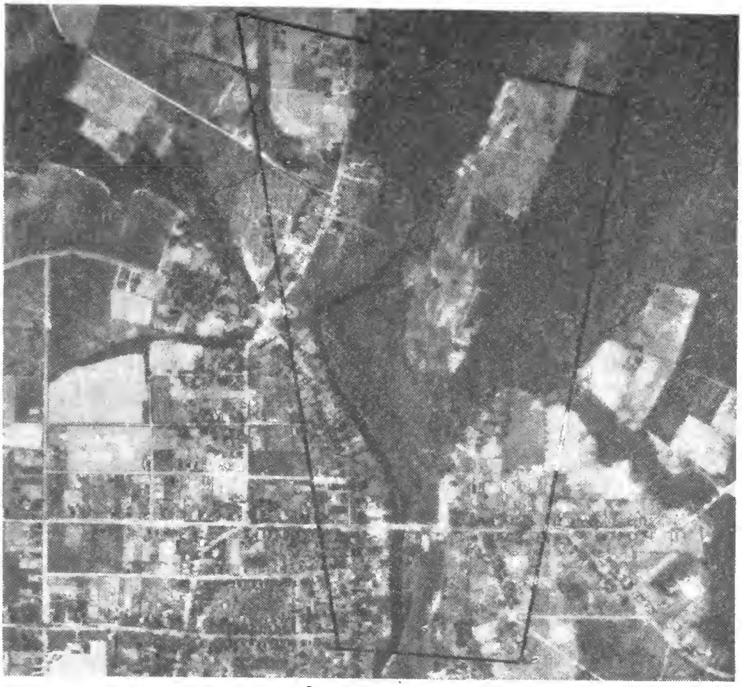


① 9 by 9 vertical from K–3B camera.



② Five-lens composite from T–3A camera.

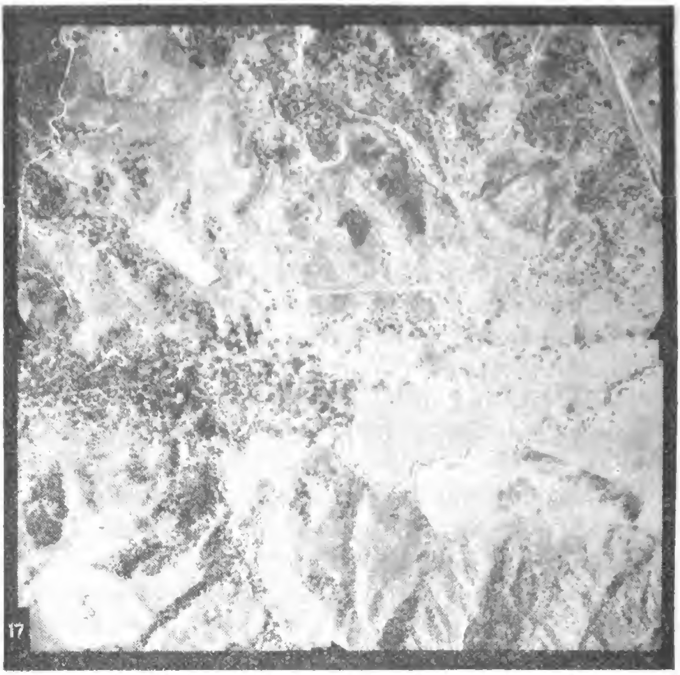
FIGURE 90.



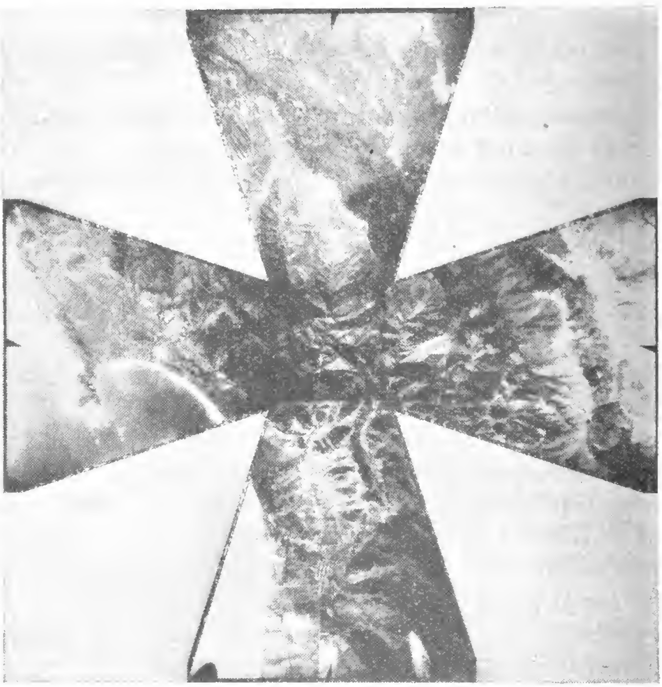
① Vertical.

② Oblique.

FIGURE 91.—Photographs of same area.

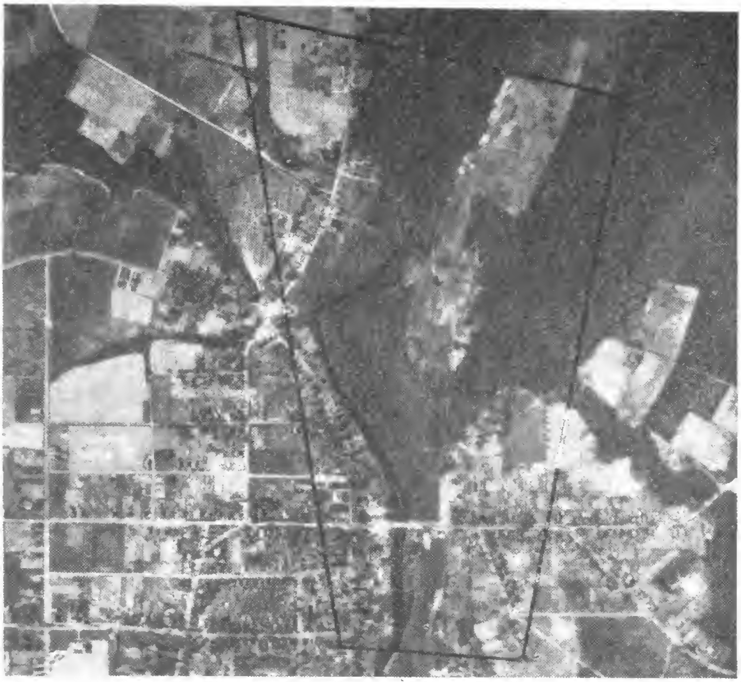


① 9 by 9 vertical from K–3B camera.



② Five-lens composite from T–3A camera.

FIGURE 90.



① Vertical.

② Oblique.

FIGURE 91.—Photographs of same area.

as nearly vertical as possible. If the ground were flat and the film truly horizontal, the result would be a photographic map of uniform scale. Since neither condition is fulfilled, distortions in the photographs usually occur. Distortions caused by tilting the camera can be almost eliminated through careful coordination between the pilot and observer.

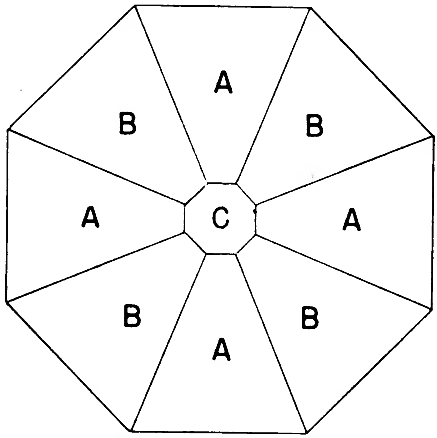
b. Obliques.—(1) Oblique aerial photographs are taken at comparatively low altitudes by intentionally tilting the optical axis of the camera from the vertical. The oblique photograph itself is rectangular, while the area of the ground it covers is a trapezium or trapezoid. Therefore the scale is nowhere the same (fig. 91 ②), since the terrain shown at the bottom of the photograph is nearer the camera than that shown at the top.

(2) Obliques which show the horizon are high obliques, and those which do not are low obliques. Obliques are used singly, except with certain compound stereoscopes of special design. Though distances cannot be scaled from such photographs, small scale maps are being made from them by several different geometrical methods. Some of the methods used in mapping from high obliques may be adapted for obtaining spot heights for contouring verticals. An oblique photograph may be very valuable for studying the terrain to be covered in an attack, and for the information and guidance of units making the attack.

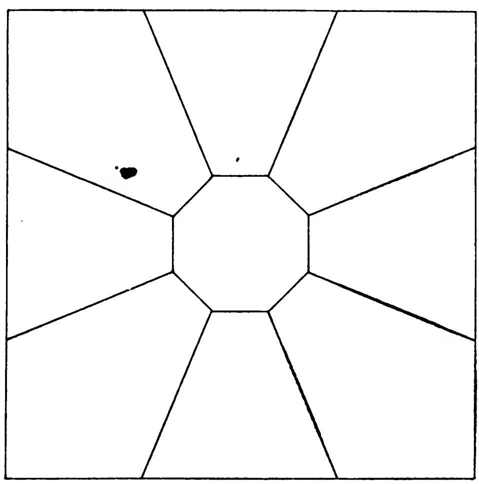
c. Composites.—(1) A composite photograph as shown in figure 90 ② and indicated by the diagrams in figure 92 is one made by joining several photographs, both verticals and obliques, transformed to a common plane, which have been taken from a single camera position. The Air Corps T–3A camera has one center chamber, the optical axis of which is held in a vertical position at exposure, and four oblique chambers, one on each side of the center chamber and tilted at angles thereto. The result of a single exposure with this camera is a vertical, which is trimmed to a size of 5.4 by 5.4 inches, and four obliques. The over-all size of the resulting Maltese cross is approximately 32 by 32 inches (fig. 90 ②).

(2) A nine-lens composite (fig. 92 ①) is made with the tandem camera which consists of two T–3A cameras mounted side by side with the oblique axes of one turned at 45° with respect to those of the other. The central chamber of one camera is not used. The four wing photographs (A) of one composite fill the spaces between the wings (B) of the other, thus forming an octagon about the vertical (C) at the center. A photograph of a large area is produced much more quickly by this

method than by the construction of a mosaic (sec. XXII), by which a number of verticals have to be cut and fitted together.



① Diagram of T-3A tandem-mounted nine-lens composite (actual size 32.3 inches over all).



② Diagram of composite from U. S. Coast and Geodetic Survey nine-lens aerial camera (actual size 36 inches square).

FIGURE 92.

(3) The U. S. Coast and Geodetic Survey nine-lens camera is made with eight chambers of obliques, grouped symmetrically about a central chamber for the vertical. All nine exposures are made on a single square film. The corners of the octagon are masked off during the process of transformation. The resulting print is about 36 inches square (fig. 92 ②).

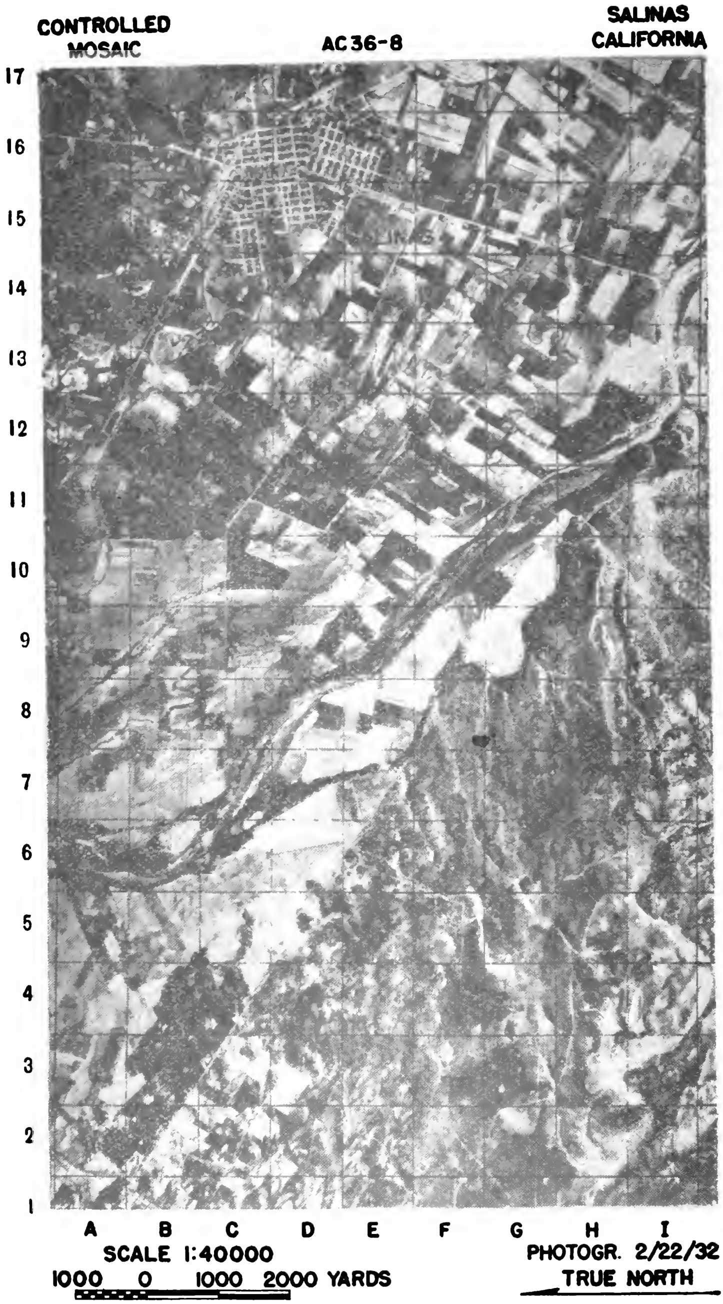


FIGURE 93.—Controlled mosaic.

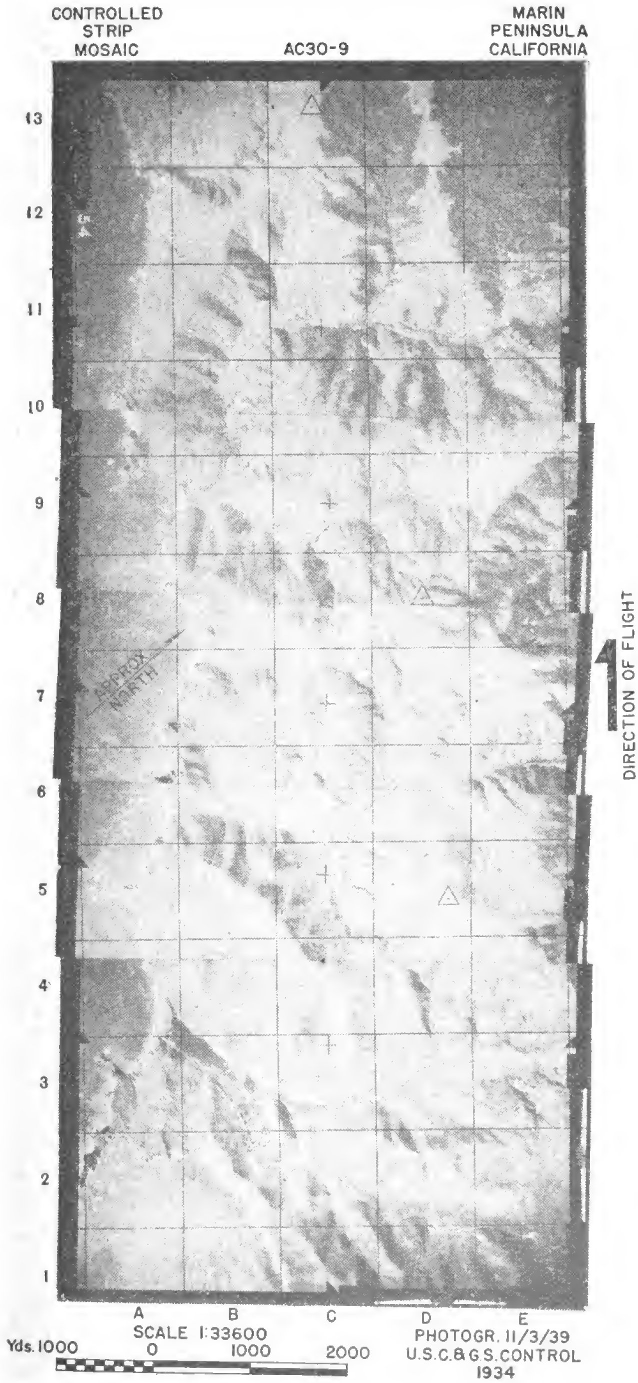


FIGURE 94.—Strip mosaic.

d. Mosaics.—(1) A mosaic is a photomap prepared by fitting parts of overlapping verticals and mounting them together. The inherent errors of each of the component pictures persist in the final mosaic.

(2) An uncontrolled mosaic (par. 42) is produced by hasty methods of joining the photographs without adjusting them into a system of ground control points. It gives a good pictorial effect of the terrain but may contain serious errors of scale and direction.

(3) In a controlled mosaic (sec. XXII) the photographs are placed by fitting them to a control plot which has been adjusted to ground control. Its accuracy as a map is in proportion to the quality of the photographs, the degree of care used in its preparation, and the density of the ground control. Figure 93 illustrates a controlled mosaic.

(4) Successive overlapping photographs made from an airplane flying a selected course or direction constitute a photographic strip. Vertical photographs are usually taken in such strips with an overlap of approximately 60 percent between successive pictures forming the strip. A strip mosaic (par. 41) is compiled by laying one strip of verticals taken on a single flight to a partial control effected by matching images of corresponding points generally along the lines joining the centers of adjacent pictures (fig. 94).

e. Stereo-pair.—Two verticals of like scale and taken in such a way that the pictures overlap and show the same terrain for 30 to 60 percent of their areas are referred to as overlapping photographs or a stereo-pair. Two such photos may be used to give the effect of actual relief when properly placed and stereoptically examined.

f. Stereo-triplet.—Three verticals of like scale taken so that the entire area of the middle picture is covered by the sum of the overlaps of the other two are called stereo-triplets (fig. 95).

g. Wide-angle.—The 90-degree wide-angle lens has been perfected in order to obtain greater coverage than is possible with usual single-lens aerial cameras, and to avoid the necessity and attendant inaccuracy of jointly mounting component prints of multiple-lens composites. The focal length of the Air Corps wide-angle camera is 6 inches, and prints are 9 by 9 inches. At 1:40,000 the area shown in each print is 6 miles square or 36 square miles. Photographic quality permits most of the detail to be readily identified and plotted at a 1:40,000 scale. The Field Artillery has found that 1:20,000 enlargements (18 by 18 inches) from these negatives are more satisfactory as firing charts than any other present type of photomap. The sharp detail and additional area covered by a single photograph increase production and improve accuracy in all methods of photomapping. Hence,

FIGURE 95.—Stereo-triplet.

it appears likely that the wide-angle camera will replace present types of cameras for mapping purposes.

28. Scale determination.—*a. General.*—The scales of vertical photographs are dependent principally upon the variable and uncertain factors of lens height, camera tilt, and relief of the ground in the photographic field at the moment of exposure. The scale of a vertical photograph, therefore, not only changes on the several photographs of an overlapping series but also is not uniform in any one photograph. Taking—

RF = representative fraction
h = mean elevation of the terrain shown in the photograph
H = altitude of plane above mean sea level
f = focal length of the lens
d = distance between two points on the photograph
M = the corresponding distance on the map
D = the corresponding distance on the ground
l = length of photograph in direction of flight
w = width across the photograph
A = ground area covered

all expressed in the same linear units (feet, yards, kilometers, etc.), the scale of a photo may be found as follows:

(1) *By lens height.*—(See fig. 96.)

$$RF = \frac{ab}{AB} = \frac{d}{D}$$

or by similar triangles

$$RF = \frac{d}{D} = \frac{f}{H-h}$$

Example: Given $f = 8\frac{1}{4}$ inches, $H = 18{,}000$ feet, and $h = 1{,}500$ feet, then

$$RF = \frac{8\frac{1}{4} \times \frac{1}{12}}{18{,}000 - 1{,}500} = \frac{1}{24{,}000} \text{ (approximate scale of photo).}$$

(2) *By comparison with map.*—The scale determined as in (1) above would be the true scale of the entire photograph under the conditions of absolutely accurate altimeter records, complete absence of tilt, and perfectly level terrain. Altimeter records, giving height of airplane above sea level, if available, are often appreciably affected by local atmospheric conditions, and the effects of tilt and relief will usually cause some scale variation within the limits of the photograph. For this reason scale can be determined more accurately by comparing distances measured on the photograph with corresponding distances either on a map or on the ground. Such

distances should be between points which are well-defined both on the photograph and on the map or ground. When it is desired to apply the scale to the entire photograph, the distances measured on the photograph should be long enough and so located as to represent the average scale of the photograph. Since the effect of tilt is radial

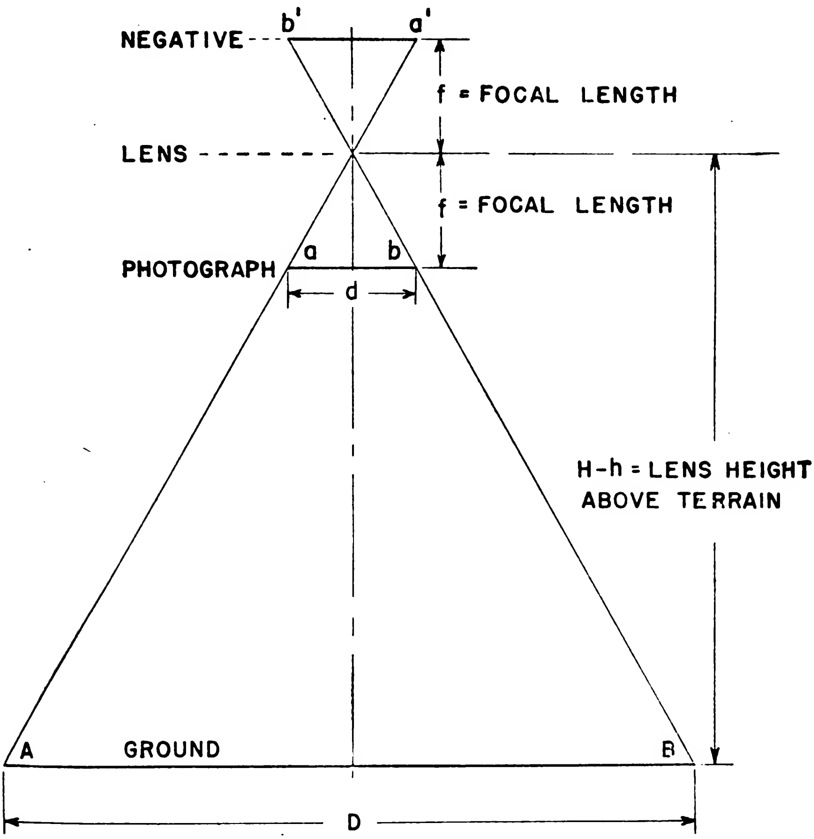


FIGURE 96.—Relation of scale, focal length, and lens height.

with respect to the center of the photograph and compensating on opposite sides of the photograph, the scale line should pass near its center. In order that the scale determination will not be affected unduly by relief, care should be taken that there is not a pronounced difference in relief between the points at the ends of the scale line. Although for terrain of low relief one such well-chosen scale line will often suffice, it is preferable that the average scale of the photo-

graph be determined from two or more scale lines. Then, the *RF* of any scale line $=\frac{d}{m}\times RF$ of map, and the average *RF* of the photograph will be the average of the *RF*'s of the scale lines.

Example: Given—

Distance *AB* on photo = 8 inches
AB on map = 6 inches
CD on photo = 9 inches
CD on map = 6.65 inches
RF of map = 1:20,000

Using scale line *AB*

$$RF=\frac{8}{6\times 20{,}000}=\frac{1}{15{,}000}$$

FIGURE 97.—Selection of scale lines.

Using scale line CD

$$RF=\frac{9}{6.65\times 20{,}000}=\frac{1}{14{,}778}$$

$$\text{Average } RF \text{ of the photo}=\frac{1}{1/2(15{,}000-14{,}778)}=\frac{1}{14{,}889}$$

For ordinary purposes a 1:15,000 scale will serve in measuring distances on the photograph used in this case. (See fig. 97.)

b. Area covered.—Remembering that all measurements must be expressed in the same linear units, the area covered by a vertical can be calculated by either of the following expressions:

$$A=\frac{w(H-h)}{f}\times\frac{l(H-h)}{f}=\frac{wl(H-h)^2}{(f)^2}$$

$$A=\frac{w}{RF}\times\frac{l}{RF}=\frac{wl}{(RF)^2}$$

c. Effective coverage.—To find the effective coverage of a vertical it is necessary to reduce both the length (l) and width (w) of the photograph by the amounts of overlap and sidelap. With the usual 60 percent overlap and 30 percent sidelap, the effective length is reduced 60 percent and the effective width 30 percent. The effective coverage of the vertical is therefore

$$\frac{.4l\times .7w}{(RF)^2}=\frac{.28wl}{(RF)^2}$$

or 28 percent of the entire area A shown by the photograph.

29. Identification.—*a.* The following information appears on the margin of a photograph when it is received from the Air Corps:

(1) *Index number.*—An index number appears on each photograph. This number identifies the picture in the series or flight to which it pertains.

(2) *Collimating marks.*—Ticks on the border of the photograph form collimating marks by means of which the principal point, that is, intersection of the lens axis with the plane of the photograph, can be determined. The principal point is the approximate center point of the contact print. Some collimating marks indicate the direction of flight by a small arrow.

b. Usually the following information is furnished on an index map, on the photo, or on a form supplied with the photographs:

(1) Date and hour of flight.

(2) Altitude. (This is only an approximate figure and cannot be used in determining accurately the scale of the photograph.)

(3) Type and focal length of the camera.

(4) Flight location.

c. If photographs have to be taken into the field, time may be saved by marking on the back, near each edge, the number of the print which joins it on that side. In any case, loose prints should always be kept in numerical or other systematic order so as to be quickly available.

Section VI

DETAIL FROM AERIAL PHOTOGRAPHS

30. General.—*a. Topographical interpretation.*—(1) Topographical interpretation is the art of identifying visible features of terrain from their images on a photograph, or in deducing the existence of hidden features by their characteristic effects on images of visible features. The best aid in this work is the stereoscope (see sec. VII). Stereoscopes and overlapping photographs may not be always available. A valuable aid for interpretation is the ordinary reading glass. Skill in interpretation results from experience in dealing with photographs of all sorts, comparing them with maps, and, best of all, with the terrain itself. The early practice should begin with prints of about 1:20,000 scale, as correct interpretation of features at scales smaller than 1:30,000 may be uncertain or quite difficult.

(2) Roads, railroads, houses, woods, brush, orchards, cultivated lands, etc., are easily identified and, in general, closely resemble the conventional signs by which they are represented on maps. On the other hand, the existence of a small stream in heavy woods is inferred from the irregular variation in the density of the woods and association with visible parts of the local drainage net. Likewise, the existence of an invisible stream may be inferred from the narrow, irregular band of brush or trees through cultivated lands, and the existence of a fence or land subdivision from a straight hedge line. Works of man are usually bounded by straight lines or regular curves and hence are easier to identify than natural objects.

b. Tone.—The shade of grey in which an object appears is known as the tone of the image. It is due almost entirely to the amount of light which is reflected by the object to the camera. The amount of light reflected depends upon the nature and texture of the surface

and the angle at which it reflects light toward the camera. Therefore, the tone of an object on two consecutive photographs of a strip will vary because the reflection of the sun's rays on the two photographs will not be at the same angle. Because of the preponderant effect of texture, the tone of objects will often appear much lighter or darker than the color would appear to warrant.

The following tone effects should be understood:

(1) A smooth surface is a good reflector of light and appears white when the camera is in a position to catch the reflected rays of the sun. However, if the light is not reflected to the camera, a smooth surface will be dark. The image of smooth water, which is an example of such a surface, is found sometimes to appear to be light and sometimes to be dark depending upon the angle at which the sun's rays fall upon it.

(2) Roads, unless tarred or oiled, are by nature good reflectors of light and possess a surface sufficiently rough in texture to reflect light through a wide range in position of the sun. As a result, roads almost invariably show as a light line or band.

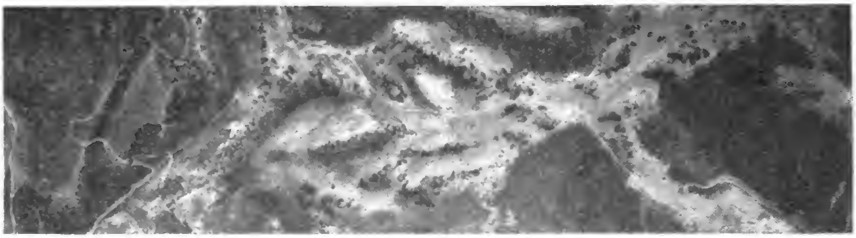
(3) The majority of natural surfaces reflect light in all directions and appear intermediate in tone because some of the reflected light finds its way to the camera.

(4) Any change in the texture or position of an object is evident on an aerial photograph through a resulting difference in tone when compared with the other positions. Thus the trampling of a field of grass by men walking across it alters the reflection of light and registers a difference in tone on a photograph.

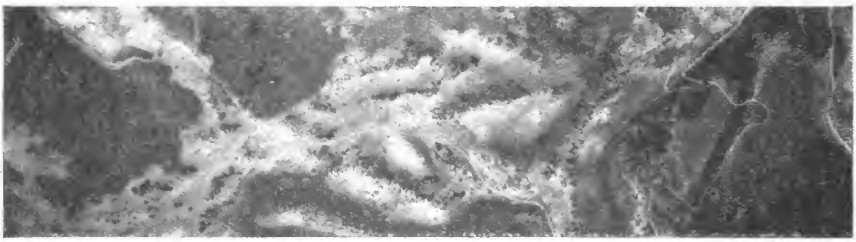
31. Light and shadow.—*a.* Aerial photographic reading and interpretation require a study of light and shadows. Hold the photograph so that the shadows fall toward you and face the source of light (window or lamp). With the photograph held in this manner, the light falling upon it is in the same relative position with respect to the photograph that the sun was with respect to the ground at the time the photograph was taken. If the photograph is held in this way, relief will appear natural, while if held with the shadows falling away from the eye, the relief will appear inverted; cuts will look like embankments and shell holes like mounds. (See fig. 98.)

b. Shadows may disclose the shape and size of an object even though the object itself may be unrecognizable on a vertical photograph. This is because the object's vertical dimensions shown by the shadow may be more characteristic than its horizontal dimensions which are shown by the image; or its tone may blend into the surrounding landscape, while its shadow may stand out in con-

trast. Shadows will often furnish valuable military information such as the approximate height, number of spans, and type of a bridge, height of trees, shape and height of buildings, and depth of cuts, pits, and quarries.



① Correct.



② Incorrect.

FIGURE 98.—Effect of shadow upon the perception of relief. The two illustrations are identical but are turned 180° from each other.

32. Natural features.—*a. Relief.*—The relief of the ground cannot ordinarily be accurately determined from aerial photographs. Valuable information relative to relief may, however, be obtained from the photographs alone, especially on details such as ditches, dry stream beds, rolling ground, etc. Relief is revealed on photographs by shadows, stream lines and ridges, shape of cultivated fields, location of underbrush and other natural growth, curves of unimproved roads, cuts or embankments of railroads and improved roads, and patches of moisture on the ground. Continued practice in reading aerial photographs will develop the faculty of determining minor differences in elevation. (Further information on relief study will be found in sec. VII.)

b. Streams.—Streams may be recognized by their winding courses, irregular widths, and frequently by the natural growth of trees and brush along their banks. Very narrow streams may be hidden by undergrowth, but their courses may still be readily traced. Dry stream beds may be easily recognized when in the open. In woods, the exact location of small streams may be difficult, if not impossible,

to determine except by reference to a map or inspection of the ground. The visible evidences of such streams are breaks or variations in density of the forest canopy (figs. 99 and 100).

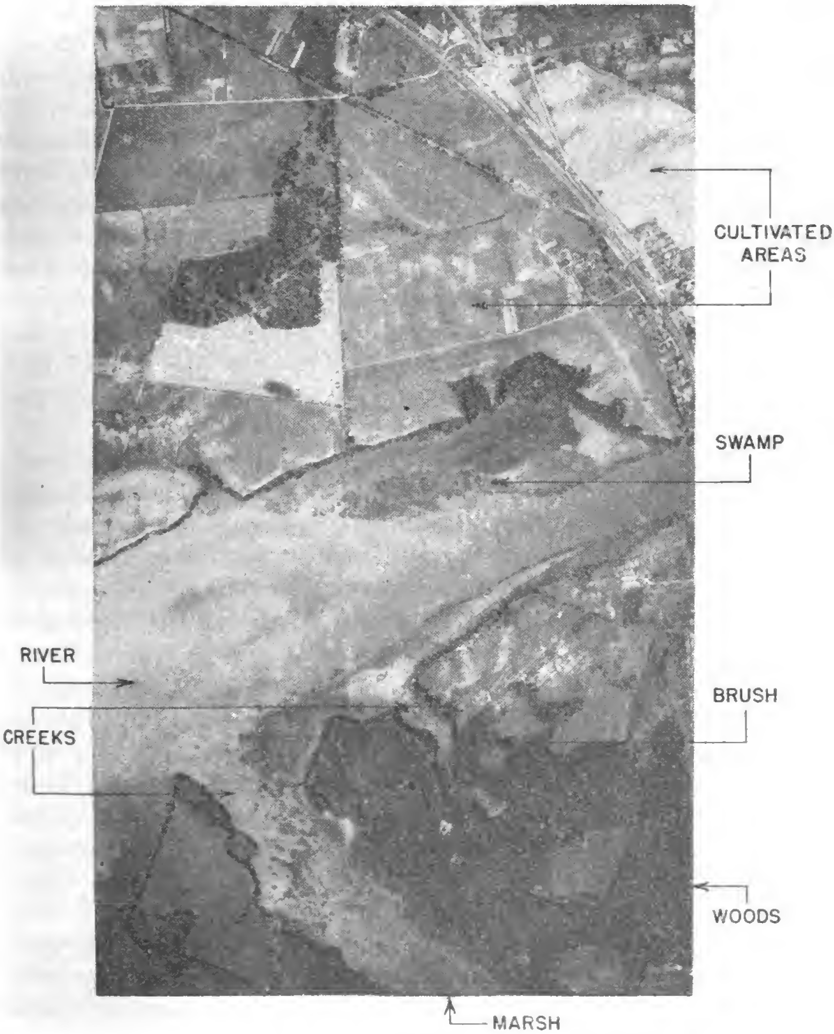


FIGURE 99.—Natural features.

c. Marshes.—Marshland or flooded areas have a characteristic appearance and are easily recognized. Generally there are channels through the marsh which have the appearance of indistinct streams with very winding courses; or they may have very many small streams which are also very irregular (fig. 99).

d. Bodies of water.—Bodies of water have a characteristic appearance, appreciably lighter or darker than the surrounding land, depending upon the amount of reflection from the surface when the photograph was made (fig. 99). Their true shape with every detail of their outline is visible. In studying the banks of bodies of water it is well to determine whether the banks are marshy or dry ground, high bluffs, or level beaches.

e. Woods and brush.—Woods on aerial photographs appear as dark masses of irregular outline. The exact shape, size, and density are much more clearly and accurately shown than on the average topographical map. Seasonal characteristics are reflected in the photographs. In winter, photographs of deciduous forests, the leafy canopy is absent, exposing substantially all ground detail which would be wholly or partially obscured in summer photographs of the same forest. Evergreen forests show dark and dense in all seasons. Brush appears similar to light woods but may be distinguished by its sparse character and lack of height and shadows (figs. 99 and 100).

f. Bluffs, quarries, etc.—Bluffs, quarries, sand dunes, gullies, washouts, etc., show their sudden changes in elevation and their depth very clearly by light and shadows. They are easily recognized.

g. Cultivation.—Fields under cultivation are clearly marked and easily distinguished from those not under cultivation. Freshly plowed fields appear very dark, due to the rough surface and the damp soil brought to the top. The nature of the crop cannot usually be determined from small-scale photographs but may be recognized on large-scale photographs. Grain in shocks is conspicuously shown by regularly spaced dots in a lighter background. Fields from which crops have been harvested show light areas. Fields with heavy standing crops and grasslands show dark areas. On large-scale photographs they present rough surface appearances. Orchards are very characteristic, the trees being planted in even rows and at regular intervals (fig. 100).

33. Civil works and structures.—*a. General.*—Anything showing on the surface of the earth that has not been put there by nature is considered structural or the work of man. While natural features occur irregularly, the works of man appear as straight or smooth curved lines, in geometrical forms in unnatural regularity and location; most prominent among these are roads, railroads, and bridges (fig. 100).

b. Roads.—These show up in general as light lines or narrow bands, the more used the lighter the appearance. Improved roads show regularity in width, long tangents, and easy curves. The hard sur-

face is clean-cut in outline and may show dark along the middle of each lane, from the oil drips of automobiles, and light along each edge. Unimproved roads show light and are of irregular width and trace with sharp turns. Evidence of condition of the road surface is usually apparent from blemishes, shadows, and color variations.

c. Paths and trails (fig. 100).—Trails have very irregular curves, vary in width, and meander more with the contours; their appearance varies with the amount of travel. Paths appear as light streaks, irregular and more or less distinct, depending upon the amount of travel.

d. Railroads (fig. 100).—Railroads are generally narrower than roads, perfectly straight between characteristic regular curves; frequently there are distinct markings, such as stations, water tanks, heavy cuts, and fills, etc., along the right-of-way. They are usually distinguishable as to number of tracks. Narrow-gage railroads have sharp turns and a less well-kept appearance than standard-gage lines.

e. Bridges (fig. 100).—Bridges are easily recognized. Usually the type of the bridge can be determined as well as the width and condition of the approaches. Small bridges may be looked for at lesser stream crossings and may be identified by the narrowing of the roadbed and the shadows cast.

f. Buildings.—Buildings are easily located on aerial photographs. Their height can be computed from their shadows and their size by the scale of the photograph. The kind and condition of the building can often be estimated. A stereoscope is helpful in picking out buildings set among scattered trees. Isolated buildings are often brought to notice by tracks leading to them.

g. Fences.—On large-scale photographs, fences are distinguished by shadows of the fence posts or walls. On small-scale photographs fences are inferred from hedge lines, section lines, outlines of cultivated lands, and the characteristics of paths, trails, and roads.

34. Military features.—*a. General.*—Military works and activities produce characteristic images and terrain effects which make aerial photographs one of the most important sources of combat intelligence. The study and analysis of information concerning the activities of the enemy as indicated on aerial photographs is a function of those entrusted with the gathering of military intelligence (G-2). This part of intelligence work is fully covered in FM 30-21. However the importance of these features in war is so great that some of them are described here for the information and guidance of those engaged in mapping from photographs. While certain characteristics will be common to all similar types of works and similar terrain


GRASS
RIVER
BRICK
KILNS
WOODS
SMALL
STREAM
SECOND
CLASS
ROADS
VILLAGE
BRIDGE
QUARRY
WOODS
RAILROAD

conditions, it must be expected that works, installations, and tactical dispositions employed by different armies and at different times or in different situations will vary in details of shape, appearance, or relative locations. Some of the details may not be identifiable on topographical photographs, which are usually of smaller scale than those used for intelligence studies.

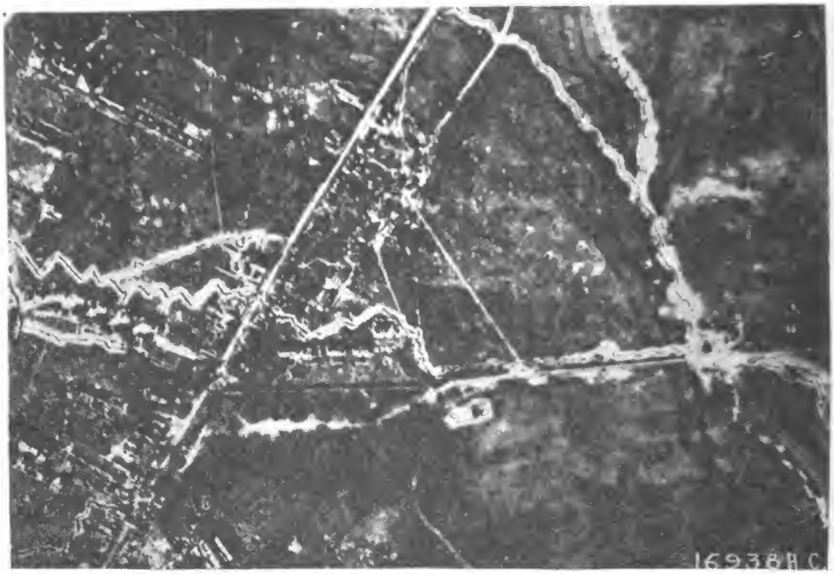
b. Paths and roads.—(1) At first impression, paths and roads may not look much like a military feature, but during military operations a path always has a meaning. It starts and ends for some particular reason and usually leads to an important place. Paths are made by more or less continuous travel from one place to another, and in war any place to which it is necessary for men to go is important enough to be investigated. For instance a path may enter a battery; by following this path back, one may find a hidden ammunition dump, which, without the path to invite attention, might have escaped notice. A study of paths on aerial photographs is sure to yield much information.

(2) All footpaths, as well as vehicle tracks, show up as small white lines more or less distinct according to the amount of travel over them. These paths may unite and form broader, heavier bands. All objects to which paths lead are possible targets.

(3) Paths will often show the outline of wire entanglements which would otherwise be hidden. They will show up the gaps or breaks in the wire, the location of listening posts and machine-gun emplacements, the location of observation posts, and many other centers of enemy activities (fig. 101).

c. Trenches.—These are readily distinguished by their characteristic traversed or zigzag trace revealed by the shadow of the trench walls or by the spoil from trench excavation. New work is generally clearly indicated by the lighter appearance of fresh earth. The density of the shadow is an indication of the depth; shallow, dummy, or incomplete trenches cast little shadow. Trenches in use are generally more distinct in outline than those not maintained in condition. Fire trenches usually have straight firing bays separated by varying traverses, while communicating trenches are generally zigzag or wavy in trace. Organized shell holes can usually be recognized by their sharpness and regularity of outline, stronger shadows due to deepening, or by paths and trenches leading to them.

d. Wire entanglements.—These show as a broad line or ribbon varying in tone from light to dark gray, depending upon the age of the belt and the contrast with the color and texture of soil and vegetation (fig. 101). The tracks made by working parties on either



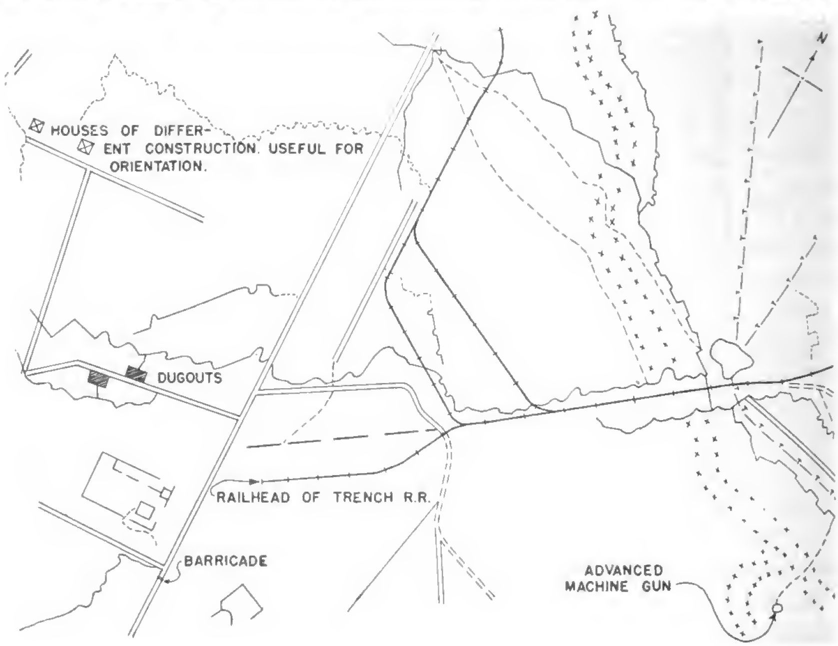


FIGURE 101.—Military features.

side of the belt of wire may be visible. Old entanglements are less distinct than new wire. Abatis and barricades, the first consisting of felled trees or brush and the latter of any available material, are two other obstacles readily recognized on photographs, especially where they appear on roads.

e. Machine guns.—Although difficult to locate, tracks often betray the presence of machine guns in open terrain. On organized ground, the evidence lies in new spoil, in regularity and depth of a shell hole, in deep shadows, in recesses along trench walls, or in the terminus of short branch trenches otherwise unexplained.

f. Observation and listening posts.—(1) Observation posts should be looked for on high ground. Their presence may be indicated by tracks leading to a command point, house or haystack, or by telephone lines, and in organized ground small trenches leading off from the main system without apparent reason.

(2) Listening posts of a trench system may look like small shell holes in front of the wire with tracks leading to them. Sometimes they may be used for machine-gun positions.

g. Shelters.—(1) Barracks are usually easily identified except when located in woods. A minute examination of woods with the stereoscope and a study of tracks will generally reveal them.

(2) Dugouts in process of construction can be spotted by the excavations and spoil. Completed dugouts are indicated by their entrances which show as black dots or notches in the parapet or firing step or on the sides of traverses. They may be disclosed by ventilating shafts, showing as black dots, and by the spoil or by tracks made by its removal. Sometimes traces of narrow-gage construction track, used to bring up material for the construction of dugouts, etc., will prove valuable aids in locating them.

h. Command posts.—These may be identified by converging trails, telephone lines, vehicles, both parked and moving, and camouflage.

i. Telephone and telegraph lines.—(1) Identification of wire lines and wireless stations will assist in locating command and observation posts, camouflaged batteries, and centrals. Pole lines show as a series of small, regularly spaced dots connected by a thin line. These are the spoil from the post holes and the tracks made by linemen. Only rarely are the shadows of the poles visible. Telephone centrals, usually in a dugout or otherwise concealed, are generally located at the junction of several wire lines.

(2) Cable trenches show as narrow, straight lines with angular changes in direction. A backfilled trench will have a fuzzy appearance due to the irregularity of the backfill.

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j. Artillery.—(1) Batteries are usually spotted on photographs by tracks leading to them or through the fact that the existing roads and trails show more usage near a battery. Battery camouflage, especially if its outline is regular, is also visible. Piles of ammunition, latrines, dugouts, or kitchens can be spotted and sometimes limbers and horse lines can be picked up. The gun is only a small part of the evidence of the existence of a battery. Batteries in the open can generally be spotted by tracks (fig. 102).

(2) When time permits, alternate battery positions are prepared for quick occupancy. A study of tracks and blast marks will usually show which positions are occupied. Roads which suddenly end in the open, or enter woods without emerging at some other points, are strong indications of a concealed battery.

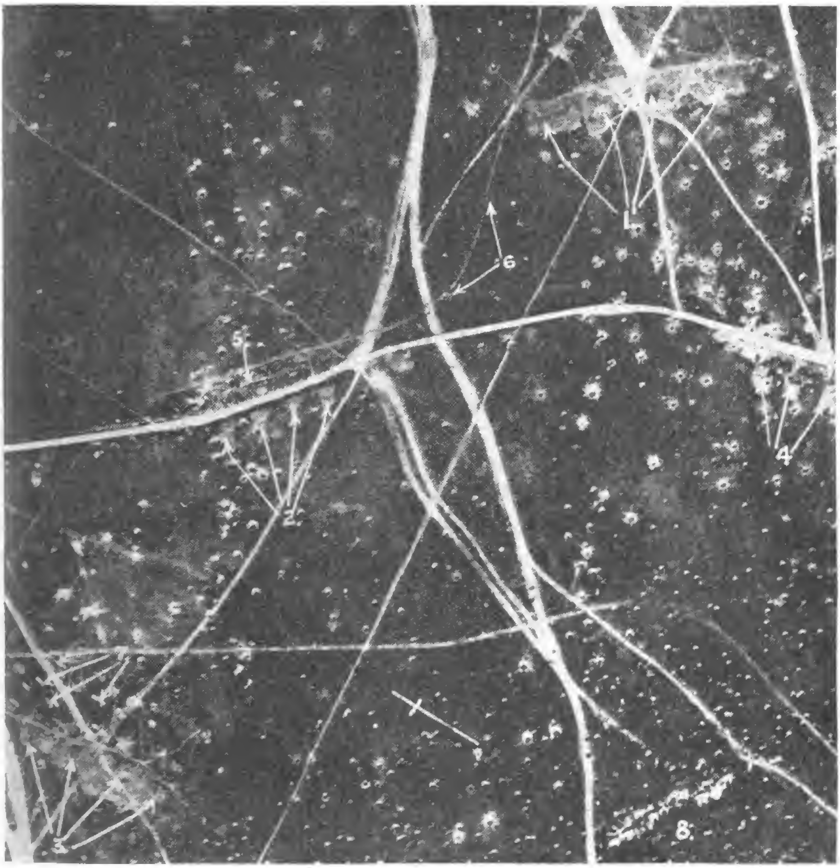
k. Antitank obstacles.—(1) In an organized position these may consist of mines placed checkerwise in ground suitable for tank movements, rows of concrete pillars, and deep trenches. Inundations, marshy ground, and deep ditches are effective natural barriers to tank movements. In searching for tank obstacles the photographs should be carefully studied for indications of such features.

(2) In mobile situations, tank obstacles may be found along roads, generally at a defile and sometimes at crossroads, consisting either of a mine, a barrier intended to hold the tank under fire, or a crater which may be covered or uncovered, possibly with the sides cut vertical. Crossroads and the adjacent fields should be carefully examined, therefore, for tank traps where the situation indicates that they might be used.

l. Rear zone installations.—(1) Offensive operations require large concentrations of troops, ammunitions, and supplies, the construction of airdromes and hospitals, the preparation of railheads, detraining points, and other facilities, all of which may be discovered on aerial photographs.

(2) Dumps are revealed by piles of material and by tracks, roads, or railroads leading to them. Supply centers are identified by searching the vicinity of suitable locations along railways and roads and by studying the activities thereon.

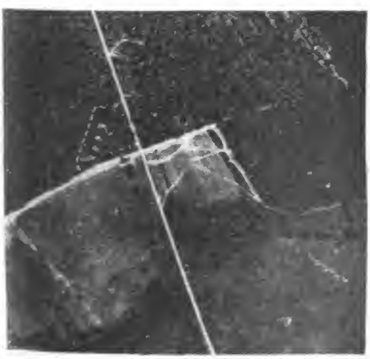
(3) Airdromes and aviation centers may be inferred from collections of hangars and the presence of landing fields and airplanes on the ground.



① Camouflaged batteries.

1, 2, 3, 4 — Batteries.

5. Trench-connecting dugouts.
6. Light railway.
7. Patches of sod removed for camouflage.
8. Abandoned position.



② Battery in woods.

③ Tracks reveal location of battery in woods.

FIGURE 102.

Section VII

USE OF SIMPLE STEREOSCOPES

35. General.—*a. Binocular vision.*—The sense of depth or volume obtained when we look with both eyes at an object is due to the fact that our eyes are separated by an interpupillary distance of from 2⅜ to 2¾ inches. Each eye registers a slightly different image of the object. The eyes adapt themselves to this use by two separate movements. They focus themselves for distinct vision at the distance from eye to object, and by convergence of the axes of vision the eyes are so directed toward the object that each image is formed on the most sensitive part of the retina. In the case of a small object held, say, at arm's length, the right eye sees the front and part of the right side of the object and the left eye sees the front and part of the left side. These two different images are combined by the brain to form a view of the object in three dimensions.

b. Stereoscopic fusion.—By holding a 10-inch piece of cardboard on edge between the two dots in figure 103, perpendicular to the page, so that only one dot is seen by each eye, and by attempting to look

FIGURE 103.—Stereoscopic fusion.

through the page, the two dots may be brought together to form a single dot in stereoscopic fusion. Thus the eyes are focused for the distance from eye to dot, while the convergence is for a greater distance. The value of the latter distance cannot be estimated by the feeling of the convergence. On varying the separation of the dots from ¾ inch apart up to the interpupillary distance, it will be found that they appear to remain fused at about the same apparent depth.

c. Correspondence.—(1) Again fusing the dots in figure 103 and keeping the head still, it will be found that, on slowly rotating the page in a horizontal plane while trying to retain the dots fused into one, the eyes will first feel strained, then the fused dot will become blurred and finally split in two, before there is much rotation.

(2) Observe that, though there is some tolerance, the fusion is easiest when the line joining the two dots is parallel to the line joining the pupils of the eyes. This line is called the "eye base." The same thing is true of any two corresponding points of detail on the two prints of a stereo-pair when viewed through the stereoscope. Pairs of images which fulfil this condition are said to be in correspondence.

d. Angle of parallax.—Since the eye base and the line between the corresponding viewed points must be parallel, the eyes, the dots, and the axes of vision all lie in the same plane for best results. Since the axes are convergent, they will meet beyond the dots. The angle at which these axes intersect is called the "angle of convergence" or the "angle of parallax."

e. Stereoscopic depth perception.—When the pairs of dots in figure 104 are fused in the same way as were those in figure 103, the image

FIGURE 104.—Stereoscopic depth perception.

obtained from *bb′* will appear to be nearer the eyes than that from *aa′*. The difference in the separation of the dots in a direction parallel with the eye base is thus associated with a difference in the apparent depth of the fused images. It is plain that the angle of convergence of the axes through *bb′* is greater than that of the axes through *aa′*, and that a difference in the angle of parallax implies a difference in stereoscopic depth. As the amount of the convergence cannot be estimated by the individual from the movement of his eyes (*b* above), the knowledge of difference in depth is not exact but relative.

f. Satellite images.—With a little practice, the dots in figures 103 and 104 can be fused without the card. It is necessary to try to look through the paper and perhaps vary the distance of the eyes from the paper slightly until fusion is obtained. Fainter dots will be observed, one on either side of each of the fused dots. These are called "satellite images" and should be disregarded. In using some types of stereoscope, satellite images sometimes appear, and care has to be taken not to confuse them with the central image showing relief.

g. Small stereograms.—The pairs of small pictures in figure 105 are really stereograms arranged for practicing stereoscopic vision without a stereoscope. At the beginning a card may be used to help gain fusion quickly. Fusion is also possible without the card, though

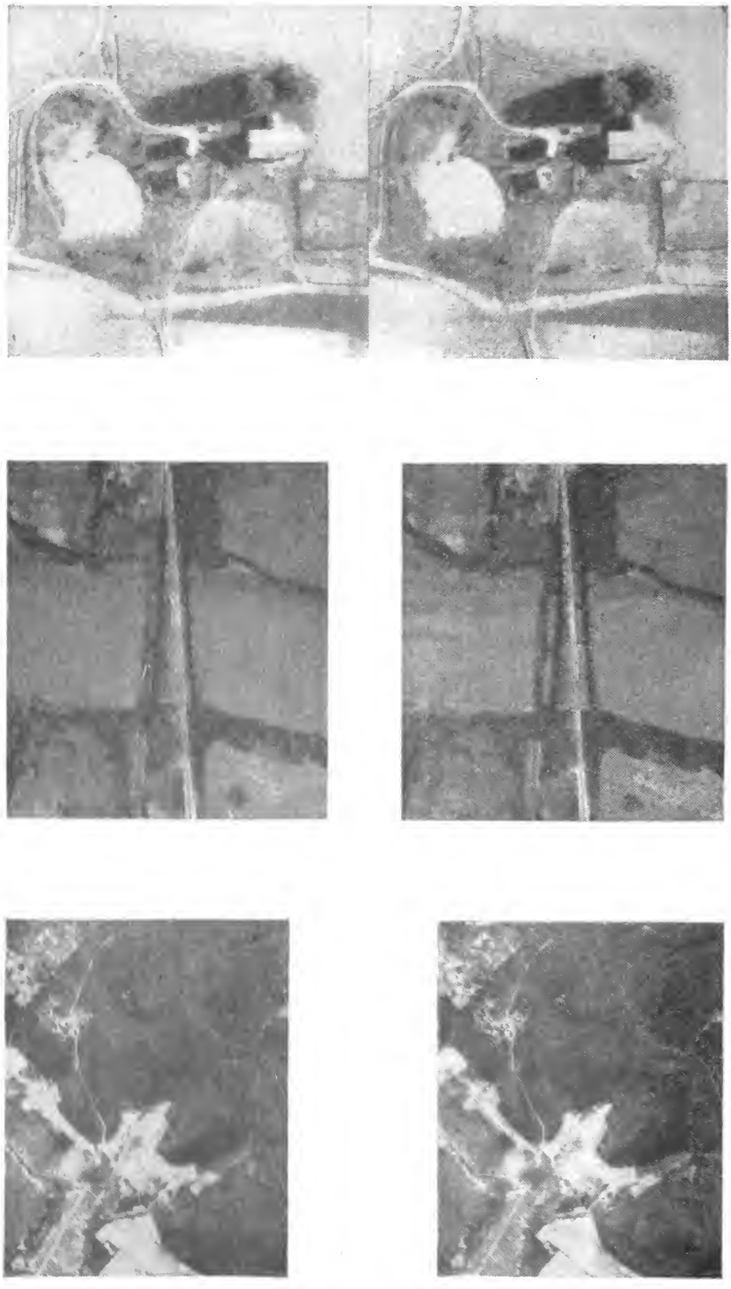


FIGURE 105.—Small stereograms.

the lower pair may present some difficulty at first. It is easy to disregard the satellite images and to look only at the middle, fused image, as the latter is somewhat plainer than the others and has the appearance of solidity and depth.

h. Difficulties of stereoscopic vision.—Everyone cannot see stereoscopically without practice. If the eyes are unequal in power, or if they are not truly set, difficulties may appear at first. However, eye glasses or eye exercises probably will correct all such faults. Most people can see stereoscopically either with or without glasses, and find their main difficulty in lack of practice, effort, and self-confidence. The accomplishment is of so much value to those engaged in military pursuits that great efforts to learn to use the stereoscope should be made. The acquisition of this ability may take a greater or less length of time, but almost every individual with good enough eyes to be in the military service can learn to see stereoscopically.

i. Two extremes to be avoided.—Most of the principles needed for understanding the use of the simple stereoscope have now been mentioned. Further experiments are not required, but the student should try varying the arrangement of the dots, the position of the head, and so on. Aside from lack of exact correspondence, it will be found that only two things seem to place any strain upon the eyes: reducing the distance from dot to eye much below 10 inches, which is the shortest distance for sharp vision for normal eyes, and separating the dots to the interpupillary distance or beyond. These unusual conditions are not encountered in using Army stereoscopes.

j. Habits for constant users.—Attention should be given to the following points:

(1) Provide adequate, even light free from glare.

(2) Keep the lenses properly focused and separated by the observer's interpupillary distance if possible.

(3) Maintain correspondence by keeping the eye base and stereoscope parallel with the line of centers (*m* below). If observance of these precautions is made habitual, the use of the stereoscope will not strain anyone with average normal eyesight, whether natural or corrected by artificial aids. Working with a stereoscope under proper conditions is no more injurious to the eyes than rifle shooting, running surveying instruments, or other occupation where the eyes are used steadily. All three develop and strengthen the eyes. The precautions given above are for the constant user of the stereoscope. Under field conditions, many who are required to observe stereoscopically only for brief periods, perhaps several times a day, will not need to follow all of the recommendations. Sometimes in the field

the proper instruments for the purpose will not be at hand, the light may be poor, the stereo-pair imperfect, and it may be necessary for the observer to hold both prints and stereoscope in his hands. Such conditions may be inconvenient, but they will not prevent the exercise of stereoscopic vision, particularly if some practice has been had under more favorable conditions.

k. Full-size overlap.—The pairs of photographs in figure 105 could have been mounted on cards and used as stereograms in the old-fashioned parlor stereoscope. However, the modified K-3B camera makes 9- by 9-inch photographs, and to view all of a 60-percent overlap without shifting the prints requires an eye base of approximately 5½ inches. Hence the direct line of sight stereoscope is not suitable for such use, and mirrors or prisms are incorporated in the several types of stereoscope adapted for viewing this and wider overlaps.

l. Increasing relief effect.—(1) All of the Army stereoscopes usually increase the relief effect in viewing stereo-pairs. The conditions of picture taking may be varied to produce a greater difference in parallax for a given difference in relief by the following means:

By an increase in the focal length of the camera.

By an increase in the length of the air base, resulting in a decrease in the overlap.

By flying at a lower altitude.

Unfortunately the practical trend of aerial photography is toward exposure conditions which will decrease the intensity of stereoscopic relief perception. Photographic altitudes are greater than they once were. A 60-percent overlap is standard for topographical work, and as it gives an air base of something like one-third of the flight altitude it is suitable for stereoscopic use. More focal length would require additional flying to cover a given area. So the improvement in showing relief through the stereoscope itself is very desirable.

(2) The mirror type stereoscope accomplishes this by enabling the observer to obtain stereoscopic vision over the whole width of the overlap, instead of a 2½-inch width as with some ordinary lens-type stereoscopes. This increases the effective length of the eye base and so enlarges the differences in the angles of parallax.

(3) With the lens types, such as the lorgnette and stereoscopic spectacles, the parallactic angle is increased in direct proportion to the magnification. The latter must not be excessive, as enlargement in excess of three times seems to blur the detail, to bring out the grain of the paper so much as to interfere with stereoscopic fusion, and to add to the distortion which is nearly always evident in simple lens types.

(4) The large magnifying type as issued is an example of a combination of lenses and prisms which is very effective in bringing up the relief. Magnification in combination with the mirror type is quite helpful if the focal length of the lenses is correct for the optical distance. In such a design, care must be taken not to introduce distortion and not to reduce the field so much as to lose the benefits generally derived from the mirror type.

(5) Anyone who uses proper glasses for reading should also use them with the various types of stereoscopes. Besides correcting the sight of both eyes to normal, the glasses may have enough magnifying effect to improve relief perception without causing distortion.

m. Procedure for stereoscopic examination.—To use stereoscopes in the most efficient manner, the following procedure should be adopted until the observer has had considerable experience. After the user has acquired sufficient knowledge and practice, many of the steps may be omitted, especially if the observations are brief and intermittent. In the field, lack of time and facilities will often prohibit following such a program in full. Even then familiarity with the detailed steps will help the observer to approximate most of the arrangements without any loss of time.

(1) Mark principal point or center of each photograph by rays through opposite collimating marks. If the latter are missing, use diagonals across corners.

(2) If possible, turn both prints so that shadows fall toward the observer and away from the light source, which the observer should face.

(3) Place overlapping part of one print approximately over corresponding portion of the other and separate them enough to uncover both. Thereafter keep the right one on the right as a safeguard against obtaining a pseudo-scopic image with relief reversed.

(4) On a line drawn on the table parallel with the edge at a convenient location for stereoscopic viewing, with needles through the principal points, pin down centers of the two prints.

(5) By rotating both prints about their centers, bring detail along line connecting centers of the two prints into correspondence.

(6) Set stereoscope into such a position that center line as seen through stereoscope becomes a single line across middle of field.

(7) If stereoscopic vision is not secured, raise or lower instrument, and, if necessary, change distance between principal points.

(8) Once fusion has been secured, allow attention to wander gradually over whole surface of overlap for several moments before attempting to form any conclusion as to relief effect.

(9) Summarizing for easy recollection:
(*a*) Mark center points.
(*b*) Shadows toward observer.
(*c*) Superimpose overlapping portions.
(*d*) Separate and pin centers on line.
(*e*) Turn into correspondence.
(*f*) Stereoscope parallel to center line.
(*g*) Vary distances until fusion is secured.
(*h*) Glance over whole overlap area.

n. Alternate or hasty method.—(1) A variation of the above method, given as the alternate or hasty method of adjusting photographs for the stereo-comparagraph in section XVIII, is equally adapted for use with the simple stereoscope. The center lines need not be drawn across the face of the photograph, but may be shown by ticks at the edges placed on the centerline already drawn on the table as in *m*(4) above.

(2) The correct separation of common points of detail for any particular setting of the stereoscope may be readily determined by observing a scale laid flat in the field of view. The graduations of the scale at a distance equal to the correct separation of common points will fuse into a single image. This distance, sometimes called the "stereoscopic base," varies with the height above the paper and with other adjustments.

(3) To avoid the transference of center points to adjacent prints as required for the method mentioned in (1) above, two other procedures are in common use for rotating centerline detail into correspondence.

(*a*) A straightedge is placed against the two needles at the principal points of the stereo-pair. The correct positions are now found by swinging each picture until corresponding features lie along the straightedge.

(*b*) In some instances, suitable points of detail on the line between centers are lacking. The stereoscope is then placed accurately over the line between the centers. By successive approximations the two prints are gradually swung into such relation that all detail along the center or base line appears to be in exact correspondence. This method will probably be chosen by an experienced observer.

(4) With most stereoscopes, viewing the whole overlap from one position of the instrument will be impossible. Several lines should be ruled on the table parallel with the base line to be used in alining the instrument after it is moved, or a series of marks for the various positions of the base of the instrument should be provided.

(5) Excessively tilted photographs cannot be brought into accurate correspondence and sometimes must be shifted as the field of view of the observer is moved from point to point. Faulty orientation of photographs of a stereo-pair with respect to one another and with respect to the eye base introduces false parallax differences and lack of correspondence. These make fusion difficult and cause distortion and diminution of relief effect.

o. Method suitable for brief inspection.—The methods discussed in *m* and *n* above should invariably be employed for any quantitative examination connected with the interpolation of elevations, the sketching of contours or even form lines, or for any long-continued work indoors, such as the transferring of center, control, and supplementary points from one photograph to the next. Abbreviated methods are more fitting for qualitative interpretation of detail, or the inspection of detail or topographical features in some particular locality. For getting the general lay of the terrain, the mirror instrument should be used, if available, as the lorgnette may cause misleading distortions. To use the hand-held lorgnette, for example—

(1) Face light source.

(2) Have shadows on both prints point toward observer, if possible.

(3) Place right overlap carefully over left.

(4) Place both photographs on map board or other flat surface.

(5) Without turning it, move right print about 2 inches to right.

(6) Have stereoscope and eyes about 6 inches above prints (keeping eye base always parallel with line between centers).

(7) Focus left eye on a fair-sized bright feature near center of left print.

(8) Move the right print slowly to right until corresponding bright feature is in view of right eye.

(9) If fusion is not obtained, vary height of lorgnette and distance between centers of prints.

(10) Rotate prints separately until fusion is easy while eyes move gradually over entire overlap.

Reading the above description takes much longer than would the actual placing of the photographs. After a little practice, fusion may be obtained immediately by rapid trial and error, and a large number of prints may be examined very quickly.

p. Types of stereoscopes; table of advantages and disadvantages.—(1) Stereoscopic spectacles increase the relief effect because of their high power. The separation of corresponding points is equal to the eye base, and it is necessary to fold the prints carefully back and

forth to cover all of a 60-percent overlap. Cutting the prints into strips would be easier but would ruin them for further use. To avoid eye strain, the spectacles should be removed before looking up from the prints.

(2) Lorgnette stereoscopes give a good relief effect over small areas, but the accompanying distortion can easily cause erroneous conclusions if a whole overlap has to be considered. The old type in the wooden frame has two advantages over the new steel-framed type: By spreading the lenses excessively, the whole width of a 60-percent overlap of 9- by 9-inch prints may be viewed; a head band of rubber can be attached with two thumb tacks, leaving both hands free to arrange the prints, etc. For continuous use, especially indoors, the lorgnette should be mounted on a stand similar to the stand for the 2-inch reading glass; then it can be focused for individual use, and the area beneath it is not obstructed by legs.

(3) The improvised stereoscope of two reading glasses crossed and tied together should be used only for the roughest work because of excessive distortion.

(4) Diopter glasses of about 3 power with 4° prism, mounted in celluloid rims, give good relief effect without very much distortion, but the effective eye base is not enough for large overlaps. They may be used as lorgnettes and also mounted on adjustable stands.

(5) The mirror stereoscope gives the largest field with the least distortion. Unfortunately the long optical distances cause an apparent reduction in the size of the images. This makes the mirror type inferior to the lens types for examination of fine details, especially on small-scale photographs.

(6) The mirror stereoscope with 2- to 3-power magnification, if properly designed to retain a large field of view without introducing distortion, would be the best model for all military purposes, not requiring extreme portability.

(7) The magnifying lens-prism type provides excellent stereoscopic impression over a small field without appreciable distortion. The support is designed to leave large, clear areas to accommodate mounted multiple-lens photographs.

(8) The table below compares the advantages and disadvantages of the various types of stereoscopes suitable for military use:

COMPARISON OF MILITARY TYPES OF STEREOSCOPES

Kind	Relative advantages	Relative disadvantages
Spectacles (high power).	Easiest to carry. Convenience. Lowest cost. Increase relief effect and enlarge detail.	Small, distorted field prohibits contouring. Stereoscopic base reduced to interpupillary distance. Easily broken oı damaged.
Folding mirror.	Practically free from distortion of any kind. Large field of view. Separation allows viewing whole overlap. Easy to maintain stereoscopic correspondence. Can be used for interpolating elevations and contours.	Case about 9 by 7 by 2 inches. Weighs 3½ pounds. Needs steady table. Legs may interfere with placing prints. Detail seems reduced on account of optical distance.
Prism diopters (6.00 spherical with 4° prism with celluloid rims).	Increases relief effect. As stereoscope, can be carried in pocket. Easiest to use in hand or on adjustable stand. Most convenient for transferring points.	Distorts less than lorgnette. About as small a field as lorgnette. Cannot get all of 5 by 9 overlap at one setting. On stand requires steady table.
Lorgnette with sliding wood frame.	Can be extended to cover 5 by 9 overlap at one setting. Increases relief effect and enlarges detail. Can be carried in pocket. Can be used in hand or with head band.	Marked distortion and small field prevent contouring. Most satisfactory with adjustable stand.
Lorgnette with steel frame.	Increases relief effect and enlarges detail. Can be carried in pocket. Can be used in hand or on legs.	About same field and distortion as with spectacles. Stereoscopic base reduced to about interpupillary distance. Legs may interfere with placing prints. Less convenient for transferring points than prism diopters.
Mirror with magnification.	Has every advantage of mirror type as issued. Field includes most of 9 by 9 overlap. Magnification increases relief effect and enlarges detail. Best all-round stereoscope for military use unless extreme portability is required.	A little heavier and bulkier than plain mirror type. Needs steady table.

COMPARISON OF MILITARY TYPES OF STEREOSCOPES—Continued

Kind	Relative advantages	Relative disadvantages
Magnifying lens prism.	Very clear vision, increasing relief effect and enlarging detail. A skilled observer can place prints for observation by others. Has individual focus for each eye and interpupillary adjustment. Can be used for mounted multiple lens photographs. By use of handwheels can be racked over whole overlap of single-lens prints.	Weighs 50 pounds in case of 2½-cubic-foot volume. Requires strong table at least 24 by 36 inches. Small field of view requires racking about overlap with two small handwheels and not enough of overlap is in view to permit ready contouring or interpolating elevations. Really is no better than mirror with magnification.

q. Aids for first perception of stereoscopic relief.—Most persons see stereoscopically at the first trial. Some have to make several attempts. Excellence with this instrument seems to depend upon good eyesight (perhaps corrected with glasses) and perseverance. Some of the methods which may help to get the relief impression are given below. As many of them as can be demonstrated with the available equipment should be tried repeatedly. Encourage the beginner to—

(1) Get control of the eyes through exercises with small stereograms.

(2) Use a lens stereoscope with the stereogram in figure 106. Have someone set this instrument on an adjustable stand for his own eyes. Then let the beginner try by gradual modifications to gain stereoscopic fusion.

(3) For use with the mirror, select a stereo-pair of good contrast and fair relief which has the line of centers about parallel with the top and bottom of the prints, or trim the right-hand print so that the edges are parallel with its center line. By the precise method of *m* above, have someone set the prints with the mirror stereoscopes. Fasten the left print securely, make guides of partially driven thumb tacks for the top and bottom edges of the right print, and replace the stereoscope with its base exactly parallel with the line of centers. Then let the beginner try to obtain fusion by working the right print gradually back and forth in the guides. If a magnifying mirror stereoscope can be used, this method will hardly fail.

(4) Get stereoscopic fusion by looking through the magnifying lens prism type at prints set for the instrument by the precise method. He has only to focus each of the eyepieces separately and adjust them to his interpupillary distance.

(5) If all else fails, try the anaglyph (fig. 107) described in *r* below. Let the beginner secure the pseudoscopic effect with the color filters, both correct and reversed.

(6) If necessary, repeat this whole program, remembering that both the light and the shadows fall toward the observer.

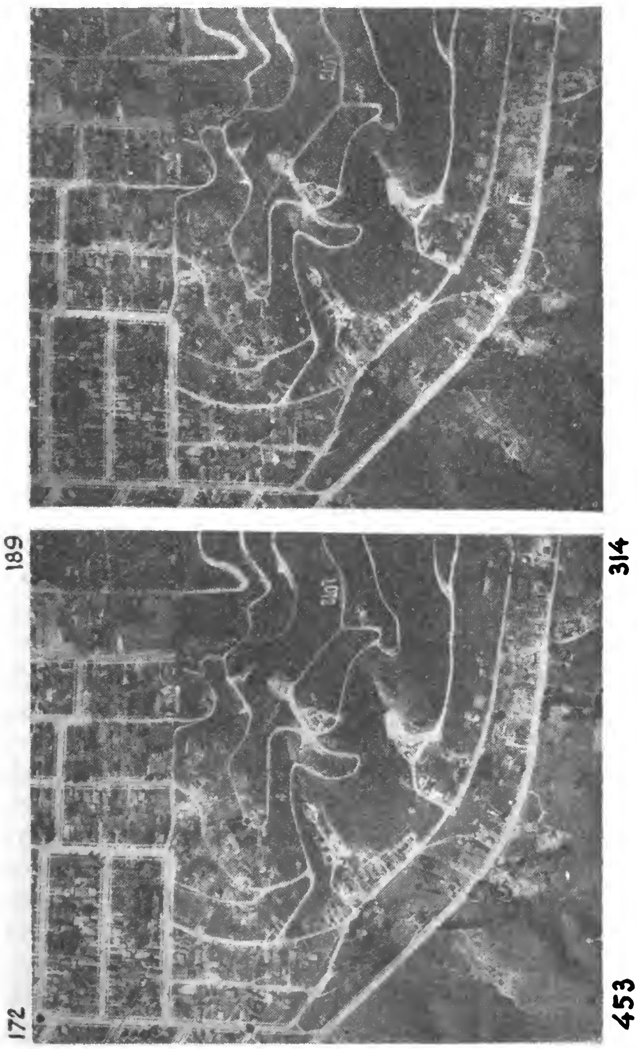


FIGURE 106.—Stereogram.

r. Anaglyph.—(1) The anaglyph illustrates a method, other than stereoscopic, of reproducing the conditions of binocular vision with overlapping aerial photographs. (See fig. 107 ①.) The term is

defined as a kind of picture resulting from the printing of two images, nearly in superposition, one (left) in blue-green and the other (right) in red, which will give a stereoscopic effect when viewed through a pair of colored glasses of opposite complimentary color—left lens red, right lens blue-green. This dichromatic printing and accompanying special glasses reproduce all conditions for binocular three-dimensional perception. The different survey viewpoint of the two photographs is recorded by printing them nearly in superposition; the principal point base lines of the two pictures are superposed with a variable separation along this line. The resulting parallax may be made that of true-to-scale restitution or deliberately distorted in order to augment the relief effect. The eyes are placed parallel to the principal point base. Each eye is presented with its own special picture: The left eye, looking through the red lens, can see only the blue-green (left) picture. The fusion of the two pictures and their colors causes the eyes to see only one view, in black and white as in the original photographs, with detail in relief. By reversing the glasses or turning the anaglyph upside down, the pseudoscopic effect will be obtained.

NOTE.—A color filter card will be found in pocket at back of manual.

(2) The effect of most anaglyphs is better in daylight than under electric illumination, doubtless because the inks are matched to the color filters by daylight. It must be understood that the anaglyph serves no practical purpose; it is included here merely as an instructional aid in attaining stereoscopic fusion. In the anaglyphic map (fig. 107 ②), the same principle is employed to obtain stereoscopic vision of relief. This map is usually made by stereoscopically photographing a relief model on which contours or form lines are indicated. The anaglyphic map, like the ordinary anaglyph, has no practical value, due to lack of clarity and blurring of detail when viewed without a color filter.

s. Improving stereoscopic faculties.—When the beginner has confirmed his ability to secure fusion readily with the various types of instruments by the several precise and rapid methods, he should study the stereoscopic models in comparison with the map and better still with the ground itself. The certainty of identification of points of detail will be increased. By tracing out the drainage system to its sources, and following the ridges and spurs to the stream junctions, the stereoscopic sense will be rapidly improved and an appreciation of the value of choosing the best method of viewing any particular features will be formed. Very soon he will be ready to perform practical work

with the stereoscope. If he has sketched or run a plane table he will see what advantages the use of photographs gives the topographer.

t. Best scales for topographic purposes.—(1) While the identification of detail is easiest on photographs of large scale, the medium scales, around 1:20,000, are better for topographic interpretation, especially with respect to the rapid interpolation of elevations and contouring.

(2) Smaller scale photos are not always a disadvantage for sketching form lines because large features are then more often seen entirely within a single overlap. As soon as some confidence is gained with the medium scales, the smaller ones should be tried. When the problem of smaller scale work becomes too difficult, enlargements can be made for the identification of important details.

u. Means of aiding stereoscopic perception.—(1) Sometimes the difference in scale between two photographs may be so different as to make fusion difficult. Some mirror stereoscopes have adjustments for sufficient change of optical distance to bring the two to the same apparent scale. The same effect is achieved by raising that part of the table supporting the smaller scale photograph or by placing books under it.

(2) The pseudostereoscopic image may be useful in certain cases where stream location is difficult. Some of the large compound instruments have means of reversing the relief effect by changing a pair of prisms. This is helpful in tracing contours through thick woods.

(3) If for any reason so much magnification is required as to show the grain of the paper, it may be possible to have a few prints made on the new opaque topographic film base, which shows no surface grain. This material is now too expensive for general use, but the flawless surface and nonshrink properties may increase the demand for it to a point where it can be made more readily available.

(4) Through the habitual use of single verticals for interpretation of detail, some may depend too much upon judging everything by shadows. With a good stereoscope, much better work can usually be done by deliberately disregarding all shadows, except in special cases where they may be of particular value in interpretation.

(5) The prints of a stereo-pair need not be of the same tone and color. In fact it may be desirable to have them different so one will show the fine details in the shadows and the other the contrast or fine details in the high lights.

36. Contours and form lines.—*a. General.*—Comparative tests have shown that the stereo-comparagraph methods described in section XVIII, if applied to photographs that are reasonably free from distortion and excessive tilt, will give results superior to any that can be expected from simple stereoscopes. Not only have the ver-

tical errors been smaller, but the stereo-comparagraph contours are usually shaped more like the actual ground forms. However, contouring with the mirror stereoscope should be practiced in preparation for emergencies when such work may be necessary. The latter method is suitable for elementary training and practice as described below. (See par. 25, FM 21-35, which describes logical contouring in detail.)

b. Spot elevations.—For best results a rather dense network of elevations should be provided. These may be obtained quite rapidly by field parties from barometer and vertical angle traverses if the terrain is accessible and time permits. In average country eight or ten well distributed elevations per square mile should suffice. If enough are available, the problem is no more serious than that confronting the topographer in the field, when handicapped by a small field of view. The plotter with the simple stereoscope has the same problem; he must have a sufficient number of elevations before interpolation can be undertaken.

c. Interpolation of elevations.—As few as four given elevations per square mile may be made to serve. The remainder must be interpolated. Preferably the best mirror stereoscope available should be used, and chance of correspondence errors should be cut to the minimum before interpolation is begun. The danger of error in this process arises from the fact that a 2° tilt of a single photograph, if carried over a mile, would cause an elevation error of nearly 100 feet. One difficulty of interpolation is that only points within the small field of distinct vision can be accurately compared. Probably the safest method in advancing from a point of known elevation to an unknown one is to move by short jumps. As a check, another determination should be made for the same point, starting from another known elevation, and using the mean of the two values as the spot elevation of the new point. Mark the elevation to the nearest foot beside each point as it is determined.

d. Critical points.—After the main framework of vertical control has been laid down by marking known elevations and interpolating additional elevations, spot heights should in the same manner be interpolated for the more important critical points such as the crests and changes of direction of ridge lines, stream junctions, and important changes of slope. Using the stereoscope, trace over all streams and drainage lines with blue pencil. As a guide, sketch in the framework of main ridge lines with soft, erasable pencil between the stream lines.

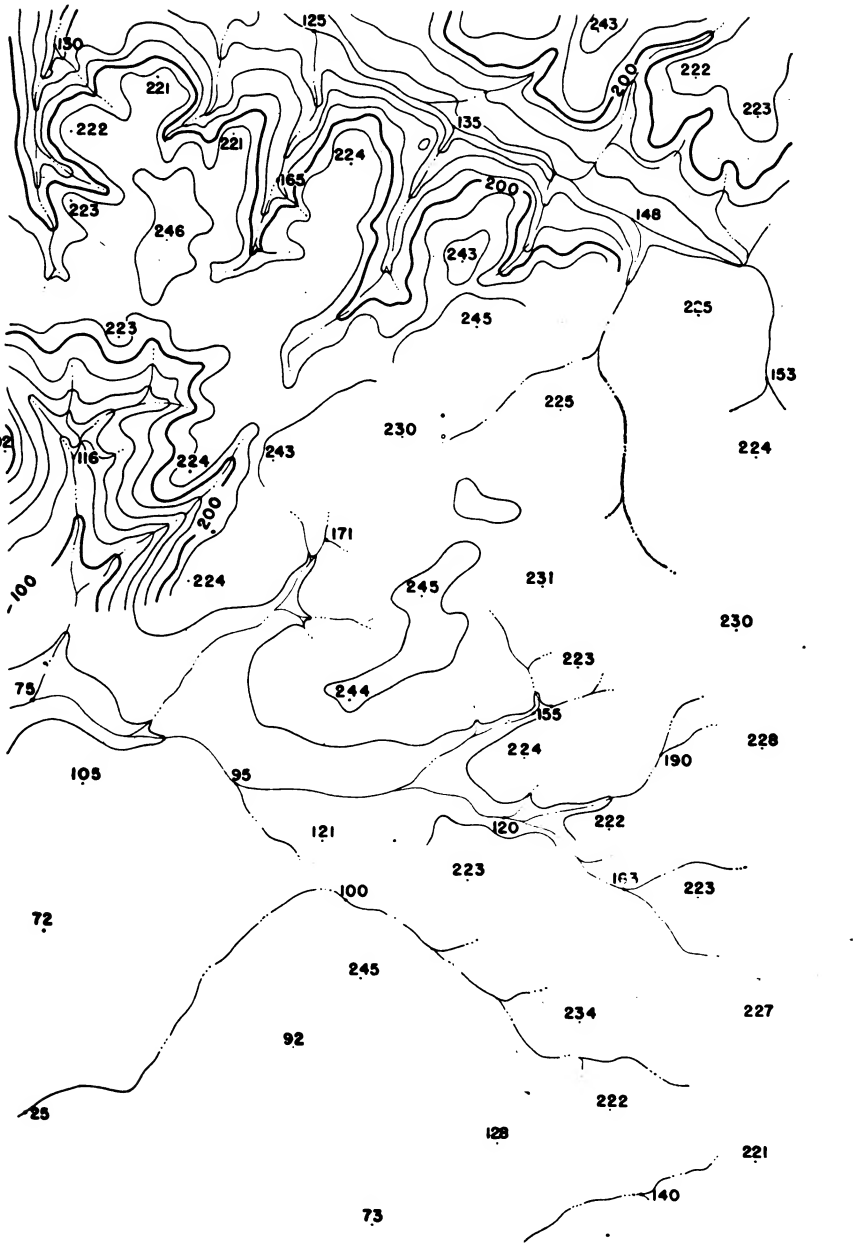


Figure 108.—Overlapping portion of K-3B photograph, partially contoured from spot elevations, showing progressive stages.

e. Contouring.—Commencing along the stream lines, and using the stereoscope to obtain the locations in accordance with the slope, interpolate every fourth contour crossing such lines. Then along the ridge lines interpolate in the same manner parts of every fourth contour near the changes of slope. With the stereoscope and following the sides of the ground forms, complete every fourth contour by connecting the parts already sketched. Inspect the whole overlap with the stereoscope to verify the positions and shapes of the contours drawn. It is best to complete the work on one large topographical feature at a time. Then complete the drawing of other contours by halving the interval and then halving again between contours already drawn. Use the stereoscope constantly to detect and correct for convex and concave slopes. Number each round-numbered fifth contour (100, 200, 300 or 250, 500, 750, etc.) and emphasize it. (See fig. 108.) Complete the work by adding the following marginal data:

(1) Descriptive title and key number.

(2) Approximate scale, by representative fraction, and graphical scale in yards or miles, or both.

(3) Date and hour of photography (as furnished with photographs).

(4) Approximate north (magnetic north if known).

(5) Direction of flight.

(6) Approximate grid coordinates of center, if available.

(7) If appropriate, a diagram or statement of any control used, together with a reference to published descriptions thereof.

(8) Name, grade, organization, and date of completion.

f. Exercise No. 14: contour interpolation problem.—Before beginning to contour with the stereoscope, the draftsman should understand contours and form lines, and how to produce them. FM 21-35 covers the principles of this work and logical contouring in detail. There can be no better training for the student of topography than practicing interpolation of contours. Until he can readily complete a skeleton by logical methods, no one should attempt the current problem. It was formerly thought that plane table sketching had to be mastered before undertaking topographical interpretation with the stereoscope. More rapid advancement can now be made with the stereoscope, since larger areas can be studied and finished so quickly that much more experience can be gained within a short time. At every opportunity, the completed sketches should be compared with a good map of the area covered. Such practice should rapidly develop stereoscopic ability and topographical sense. Exercise No. 14 consists of contouring the entire center print of a stereotriplet using

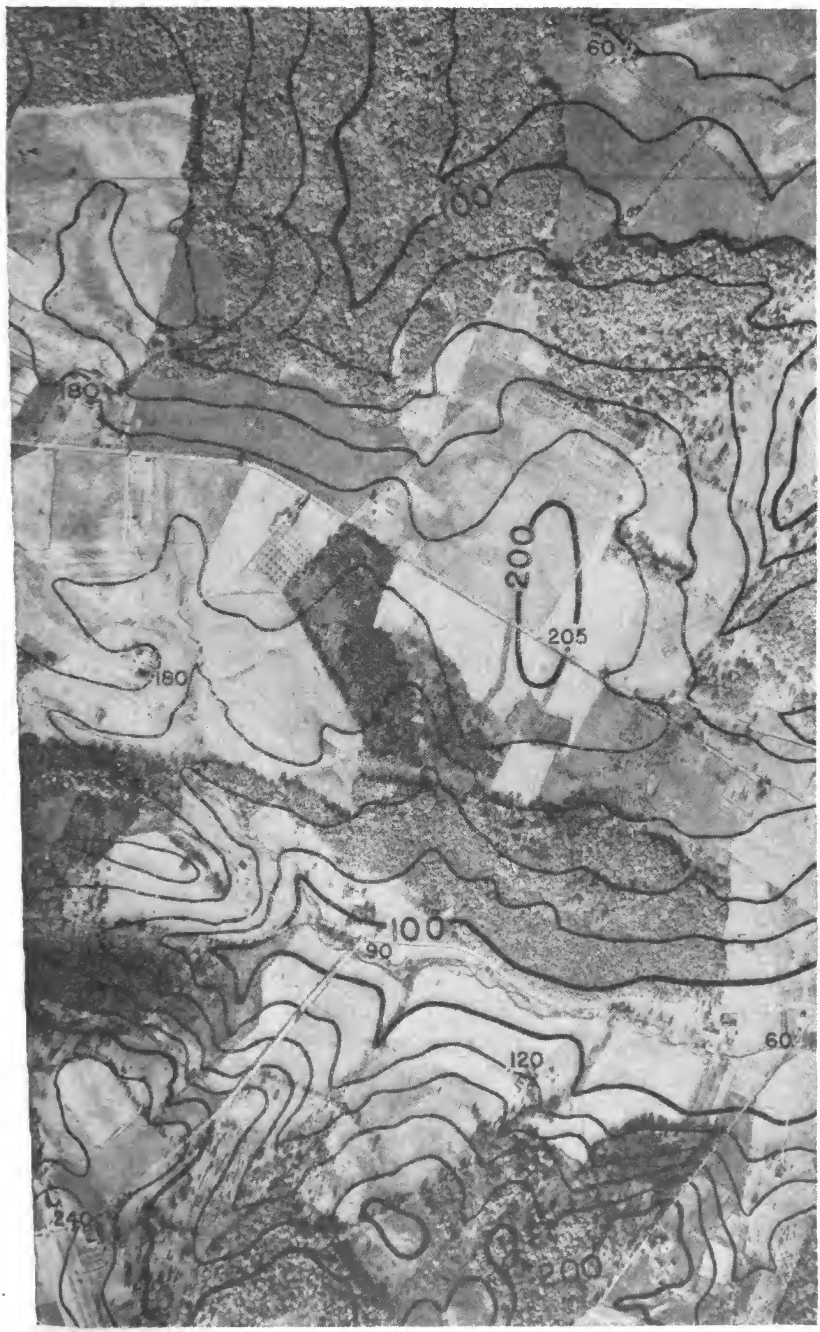


FIGURE 109.—Contour interpolation problem (exercise No. 14).

a mirror stereoscope, having given eight of ten well-distributed elevations in each square mile. By trial, choose the pencil, perhaps a 2 or 3 B, which will make legible lines without leaving furrows in the print after erasing. Study and follow step by step the instructions in *b* to *e*, inclusive, above. (See fig. 109.)

g. Form lines.—The worst possible conditions for delineating relief would arise from the military necessity to effect some sort of portrayal of the vertical relief of an area without the availability of any vertical control. It might be highly important and worth while in such a case to be able to show where up and down grades exist and that one particular feature is higher or lower than another. In practice, if a start is made on some delineated feature without any general plan to cover the entire area, the observer soon finds himself lost. The following is recommended, in strict accord with general principles of accurate procedure:

(1) Make a careful stereoscopic study or analysis of the terrain involved to fix in mind the general lay of the land. Solve the drainage system (but do not trace at this time) of the area as a prerequisite to the ability to proceed with the operation.

(2) Based on the most intelligent information or guess at hand, assign a definite figure to the maximum and minimum elevations involved in the area. If a reconnaissance could be made over the area and even barometer elevations taken, better results would be obtained.

(3) Working first along the principal master lines of the terrain (principal stream and ridge lines) and then extending over the minor ones, assign definite elevations, in conformity with the maximum and minimum elevations, to all critical points (sudden changes of slope) involved. Thus a complete elevation framework for the entire area, by natural terrain feature, is built up, which framework is relatively correct.

(4) Thereafter the procedure is the same as outlined for accurate work. Trace out in blue pencil the drainage system of the area in greatest possible detail. Working along the master lines of the terrain, take each pair of critical points in turn and interpolate every fourth ground form line (drawn as contours, at the proper contour interval, but not so marked). Then complete every fourth ground form line, paying particular attention to the drainage system, followed by the insertion of the intermediate lines by successive halving of the intervals between the lines already drawn.

(5) Indicate plainly on the map at what approximate interval vertical relief is shown by ground form lines. Indicate every fifth ground

form line by a heavier line than intermediate ones. Do not indicate a definite elevation to any ground form line. (See fig. 110.)

FIGURE 110.—Ground form line problem (exercise No. 15).

(6) Speed is essential in order to justify such procedure even as a hasty mapping method. Draftsmen cannot be allowed to waste time

in an attempt to refine the character of the work. The procedure should be accompanied with a general understanding of a specific output requirement, perhaps 1 to 3 square miles per hour on photographs of medium scale.

h. Exercise No. 15: ground form line problem.—By the methods of *g* above, the student should sketch ground form lines on the middle print of a stereo-triplet having no known elevations. Add to the marginal data (*e* above) a note indicating that ground form lines are shown and stating the approximate interval. (See fig. 110.)

37. Interpreting detail.—*a. General.*—In section VI the identification of detail on a single photograph was explained. Here it was shown that such characteristics as difference in tone, shape of shadows, and the surroundings had to be considered in arriving at an interpretation.

b. Advantages of binocular vision.—The superiority of binocular vision over the use of a single print is well shown when such objects as houses, water tanks, and lone trees not only appear to rise above the ground surface but display their shapes and relative heights. In a cluster of small terrain features on a single print, shadows often obscure the component parts. Binocular vision lifts the individual objects out of this blur and gives them distinct form. Sometimes exaggeration of the vertical component may confuse the beginner but practice will overcome that.

c. Topographical interpretation.—Paragraph 36 sets forth methods of placing photographs and stereoscope for the interpolation of elevations and the drawing of contours and form lines. These arrangements are employed for other uses of the stereoscope, if time and the situation will permit. For a quick study of a particular locality, experience will indicate the utility of more hasty methods. By these means the terrain will reveal the presence or absence of trenches or buildings, the drainage and slope of the ground, the location of cuts and fills, the suitability of a site for any particular purpose, or the route to an observing point, etc.

d. Magnification.—As the photographic scales decrease, interpretation of detail becomes more difficult. Magnification not only increases the apparent size of the points of detail but renders them more conspicuous by reason of increased relief effect.

e. Exercise No. 16: planimetric detail from photograph.—With a 3H pencil, on a piece of ivory white tracing paper (Post No. 167 or similar) of suitable size, trace the detail from an assigned photograph. Fasten the photograph securely to the drawing board.

Place the paper over the photograph and fasten the top only, so that the photograph may be readily exposed for a clearer view. Place a paper weight on the bottom edge of the paper and trace first the collimating marks and any control points marked on the photograph. These marks are used for exactly superimposing the tracing paper over the photograph, in case any interruption of work occurs. Employing the conventional signs in FM 21-30, trace all details from the photograph. Make full use of the lorgnette stereoscope, especially in completing the drainage system and in searching for buildings, bridges, cuts, fills, etc. Look for buildings near the ends of paths and roads, and in small clumps of trees. Using guide lines, letter in the body of the sheet, the names of places, streams, railways, etc., as far as available. At the bottom, letter the number of the photograph, the date, and name, grade, and organization. (See fig. 111.)

38. Drawing contours on photographs.—*a. General.*—The contouring of a single photograph has been explained in paragraph 36. A modification of those methods is necessary if a larger area is to be contoured. Several photographs of one or more strips may have to be used. In order to save time, several men may work on the different overlaps, and their work must be coordinated to avoid duplication of effort or excessive adjustments in compilation.

b. Conversion to map scale.—The simplest and quickest solution is to publish the compilation at the mean scale of the photographs. If the prescribed final scale differs from the photographic scale by less than 5 percent, the change can be made by minor adjustments during compilation. If more than 5 percent change has to be made, it may be necessary to compile a new map with the pantograph after the contouring is completed. If photographic equipment is available, time would be saved by compiling at the average scale of the prints and converting to the required map scale by copying photographically. If the map scale is larger than the photographic scale, time may be saved by procuring photographic enlargements from the original negatives before contouring.

c. Spot elevations.—Four elevations per square mile may be enough for contouring a stereo-triplet, with the careful interpolation of additional elevations. However, if work has to be joined, every effort should be made to provide more elevation data so that the individual sketches will be executed on a basis common to all. This precaution is particularly true in flat country or at the larger scales, as the error caused by tilt in the photographs may be much larger in proportion to the total difference of elevation on any stereo-pair. If field work

is possible, an increase in density of spot elevations by means of vertical angles or even barometer traverses might be undertaken.

d. Division of areas.—The photographic distortions due to tilt and relief increase materially toward the edges of the prints as will be fully discussed in section XIV. The student must remember that the central portion of any photograph should be used for map compilations, except in the rare case of having perfect photographs of practically flat terrain. In tracing detail, it is always much better to stop work halfway toward the centers of adjacent photographs. In that case the adjustments are so small that they are easily made. When stereoscopic contours are to be drawn, the individual features of topography should be completed on a single stereo-pair insofar as possible. Therefore, in laying out the areas to be contoured on each photograph, the central borders which should be used for mere planimetry are modified where convenient so that the larger features are contoured on a single print, thus simplifying the necessary adjustment during compilation.

e. Joining overlaps.—The final compilation will be simpler if the spot elevations can be more densely distributed near the borders of individual photograph areas assigned as above. As each border is finished, the contour ends should be transferred to the adjoining areas on other photographs by plotting or the matching of detail.

f. Compilation.—If time is short, the control plot can be quickly prepared by a draftsman not engaged in contouring. Infrequently, some more rapid method such as those of section VIII may have to be adopted. For best results the compilation should be by one of the methods given later in sections XVI and XVIII.

g. Distortion due to tilt and relief.—For comparatively small areas, tilt may be disregarded if sufficient spot elevations are provided to assure that the stereoscopic model will be adjusted to the correct datum. In moderate country, relief displacements may be neglected. In the more rugged types of terrain, the relief distortion of the planimetry will have to be corrected as in section XVIII. The contours on the photographs should be traced along with the planimetry, and thus be correctly located in the compilation.

h. Exercise No. 17: contours and planimetry from photographs.—Following the foregoing principles, the student should now complete a small compilation from several overlapping photographs, marked beforehand with the necessary spot elevations. The exercise will include the laying out of the area to be contoured on each of the prints; the making of a hasty control sheet on Post's No. 167 ivory white or similar tracing paper by one of the methods of section VIII; and the

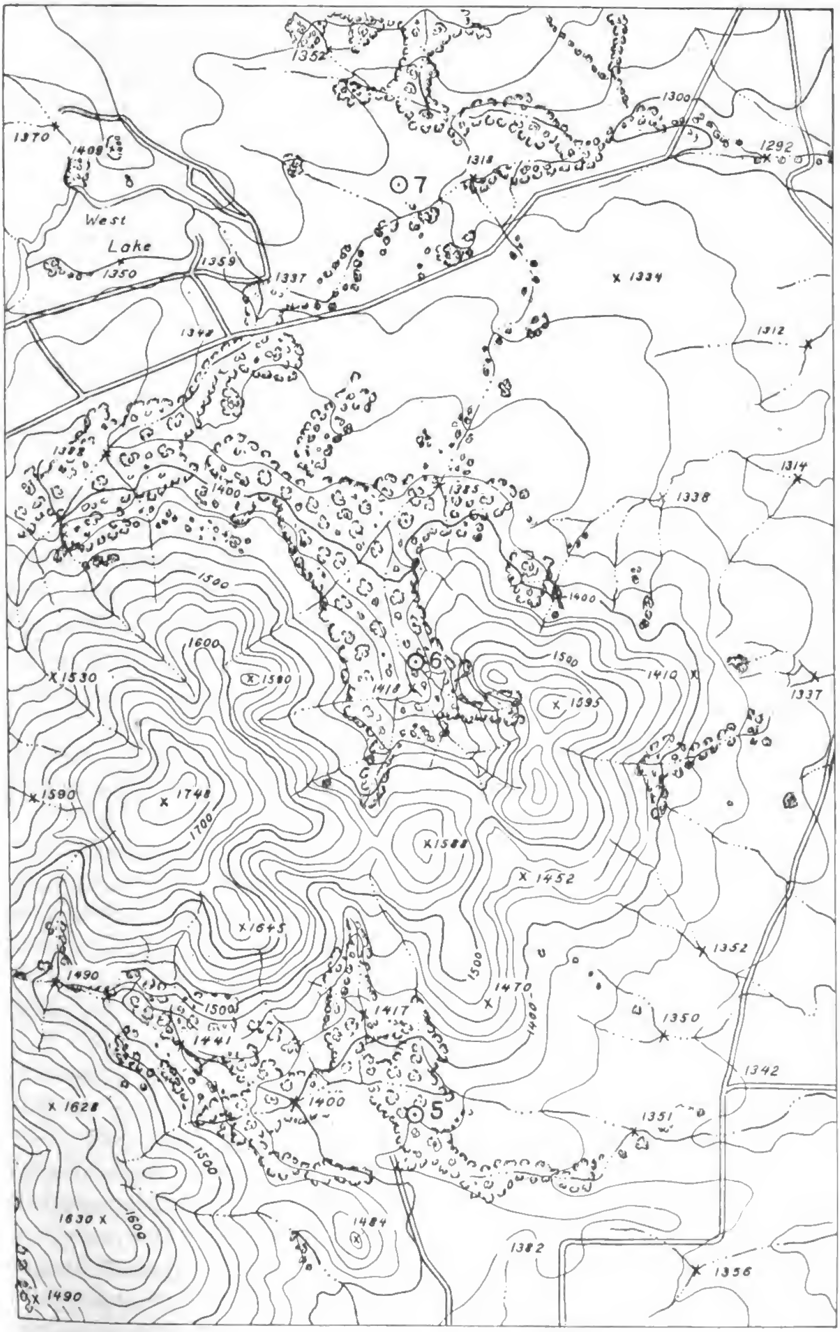


FIGURE 112.—Contours and planimetry from photographs (exercise No. 17).

compilation and adjustment of the planimetry and contours by tracing direct to the control sheet. The compilation will be finished by the lettering of place names, etc., in the body of the map, and showing in the margin all of the pertinent marginal data to conform with previous instructions.

Section VIII

HASTY MAPS FROM AERIAL PHOTOGRAPHS

39. Types of hasty maps.—*a. General.*—Usually hasty maps are made especially to serve some definite purpose. They show few details as the time for making them is strictly limited. They are utilized only until more accurate, controlled maps are available. Aerial photography has made it possible to prepare this class of map far more rapidly and more accurately than by the old sketching board methods.

b. Photomaps.—As used here, the term "photomap" will include reproductions of aerial mosaics, composites, and verticals. (See par. 6*h*, FM 30-20.) If there are time and need, contours or form lines may be drawn on the prints as described in section VII.

c. Revision of existing maps.—Old or incomplete maps may be brought up to date through the restitutional methods described in detail in section XXI.

d. Tracing from photographs.—In order to eliminate nonessential details and to secure space seldom available on photographs for additional information in the form of symbols or notes, tracings may be made from verticals or composites. These may be prepared with or without contours. (See figs. 111 and 112.)

e. Reconnaissance maps.—Reconnaissance maps of larger areas may be quickly made by the methods described in paragraph 40.

f. Strip mosaics.—Strip mosaics are laid by one of the methods of paragraph 41. They are used for artillery fire control, target designation, and other tactical purposes.

g. Uncontrolled mosaics.—Uncontrolled mosaics are useless except for the roughest kind of reconnaissance maps. A mosaic cannot be used or viewed stereoscopically even by dismounting the component prints. The latter are usually cut up and pasted solidly to the mount (par. 42), so that individual prints are badly damaged and of little use when removed.

40. Reconnaissance maps.—*a. General.*—The details of making such a map are so dependent upon its purpose and the time allowance that the prescription of any definite program or method should be made only when all of the circumstances are known. The personnel, time, means, and data at hand must all be employed in a well-coordinated effort to have the work finished in time for use, usually sooner than could be expected. Field work is reduced to the minimum justified by the urgency of the occasion. Every possible use must be made of photographs and any other data at hand. An early decision must be made on methods and the work planned so that every man contributes his full share without interfering with others. For hasty mapping operation, such as the making of reconnaissance maps, the tilt of the camera and the effect of relief need not be considered with average vertical photographs of average terrain.

b. Horizontal control.—Beyond a few points determined by plane table intersections, etc., horizontal control may be impossible. If already established and identifiable on the photographs, a couple of control points in the area may be useful in determining the average scale of the photographs and in orientation. A few points from an existing map of smaller scale may be the best data available. Perhaps a compass bearing and one roughly measured distance or, if the area is remote, knowledge of the altitude and focal length of the camera may have to suffice.

c. Vertical control.—This may be supplied through vertical angles taken in conjunction with plane table intersections, etc. Elevations by interpolation of contours on existing maps, if they are available, might have to do. The elevation of any large body of water shown on the photographs would be particularly useful. If no vertical data can be had and the map must be contoured, high and low elevations would have to be assumed and form lines interpolated. On the other hand, circumstances might permit of obtaining some elevations with barometer and clinometer.

d. Planimetry.—This can be obtained from the photographs, perhaps supplemented by field reconnaissance of any important features that may not show distinctly on the photographs. In such case, extra photographic prints with directions as to what information is needed should be given the field men to be used for controlling any sketching for which there is time.

e. Supplementary control.—Such control may be provided from the photographs using one of the methods described in section XVI. Speed might require the tracing of a frame work of roads from a mosaic hastily tacked down by matching the edges of photographs,

or even by tracing directly from the photographs by superimposing the completed work of the tracing over the corresponding part of the next photograph. In such rapid work, time can be saved by having faint or blurred detail emphasized in outline with colored pencils before tracing from the photographs.

f. Compilation.—This may have to include pieces enlarged or reduced from field sketches and photographs that have been contoured or provided with form lines. If the time is extremely short, parts of the compilation may have to be left uncontoured.

g. Completed map.—This must fulfill the purpose for which it is made. On all work of this sort, a brief note should state the data, methods, and time spent thereon in addition to the usual marginal data.

41. Strip mosaics.—*a. General.*—A strip of verticals in numerical order can be spread in a few minutes on a flat surface in such a way as to give a good idea of direction and distance along the strip. Each photograph is laid over the preceding one in such a way that the details of the overlapping portions are coincident. This might be approximated by matching the detail along the edges. A better way is to check and improve the agreement or all points of detail by rapidly raising and lowering the overlapping portion of the upper photograph until no apparent shift of detail in seen alternately on the two photographs. A strip mosaic by the method in *b* below is better than either of the foregoing methods in that a partial control is effected by matching center points on adjacent pictures.

b. Laying strip mosaic (fig. 94).—(1) Prick the principal point or center of each print, found at the crossing of short, light lines, through the two pairs of collimating marks. By comparison of detail transfer each of these center points by pricking its position onto the two adjacent prints. If the center point cannot be identified on the adjoining photograph, choose near the center a point of detail which can be identified on the next photograph and mark it carefully on both. The true center is disregarded wherever a substitute center is used. To avoid confusion, the one to be used should be circled with chalk. Each photograph, except the first and last, now has three points marked on it: Its own circled center or substitute center, and the center or substitute center of its two adjacent photographs transferred from them. By laying a straightedge through the circled point and the point near the rear or following edge of each photograph, draw a "tick" on the forward edge of the print.

(2) A piece of heavy cardboard of suitable size should be used for the mounting sheet. Paste the central portion of the first photograph of the series, properly oriented, near one end of the board. With the straightedge through the circled center and the point near the leading edges, draw a line on the mounting board a few inches beyond the space that will be covered by the second photograph. With the dividers compare the distance between the two points as taken from each photograph. If they are practically the same, no adjustment will be required, but if they differ it will be necessary to make an adjustment. This can be done best by dotting a mean position for the point near the border to be pricked through instead of the point itself when the photograph is laid down. Put the second photograph over the first photograph by pricking through the point near the border (or the dot in case an adjustment is to be made) and then setting the needle on the corresponding point of the first photograph. Swing the second photograph about the needle until the line at the border falls on the line of the mounting sheet. Paste it in this position. Proceed in the same manner for succeeding photographs. The needle may be dispensed with by trimming the second photograph at the point near the rear border.

(3) The photographs are now all in position on the mounting board. Each overlap must be cut through with a sharp knife or razor blade so that surplus pieces can be discarded. Only the central parts should be retained, not the edges. Not only are the negatives photographically best at the center, but tilt and relief distortion increase materially toward the edges. The simplest method is to cut the prints straight across halfway between the centers. This may cause duplication or omission of points of detail in hilly terrain. Such discrepancies can usually be avoided by cutting along some other line which might be diagonal or even curved, according to circumstances. The prints, until now only pasted forward of the center, are ready to be entirely pasted.

c. Use of control sheet.—If a control sheet has already been prepared by one of the methods of section XVI, it should be used, thereby saving some time and increasing the accuracy of both distance and direction. Strip mosaics will have substantially the same marginal data as described in paragraph 48*b*.

42. Uncontrolled mosaics.—If the flying were perfect and the terrain of low relief, it might be possible to join two or more strip mosaics side by side to form one of larger area. In the average case, to attempt such a procedure is not worth while unless the strips can be adjusted to ground control. Compilation by working out

from a single photograph may cause serious gaps or overlaps to appear sooner or later. When several parallel and overlapping photographs are to be made into a mosaic, that series which is most centrally located with respect to the others should be alined, as in paragraph 41*b*, and the photographs of the other series joined to it by building outward on each side. Changes in altitude of the airplane, which are difficult to avoid when flying back and forth to take several strips of photographs, will give different scales to photographs of different series which will have noticeable effect in building up the mosaic. To distribute these various scales and other discrepancies, it will be well to lay down photographs to form lateral spurs by alining them from the strip first laid down and then fill in the spaces by matching intervening photographs on two or more borders. (See fig. 93.) Uncontrolled mosaics will have substantially the same marginal data as described in paragraph 48*b*.

Section IX

INFORMATION ON MAPS AND MAPPING

43. General.—*a. Coordination of map drawing and aerial photographs.*—The Air Corps performs all aerial photographic work connected with military mapping activities according to specifications prepared by the Corps of Engineers. The Corps of Engineers prosecutes all work relating to the production of maps, etc., for military purposes. (See AR 300-15 and FM 30-20.).

b. Terminology.—(1) A map is a drawing, or reproduction of a drawing, which represents a portion of the earth's spheroidal surface on a plane. Terrain features are shown on a map by conventional signs and symbols, and their location on the map as compared with their true position on the ground usually is within the limits of accuracy of office and field work.

(2) A photograph or a combination of photographs taken vertically from the air portrays a portion of the earth's spheroidal surface on a plane in a manner similar to a map with the following exceptions:

(*a*) Features are shown photographically instead of by conventional signs.

(*b*) Distortions inherent in photographs, especially those caused by the effect of relief, cannot be entirely removed (par. 72).

(3) Aerial photographs, their negatives, or diapositives (par. 81) are nearly always used in the making of maps or in case of emergency to supplant maps.

(4) A photomap is a single vertical photograph, a composite, or a mosaic. (See pars. 39 and 41.)

c. Classification of maps.—(1) *According to scale.*—Military maps will vary from small scale planimetric maps to accurate, well-prepared topographic maps suitable for enlargement. (See par. 90.) They may include various special purpose maps, such as road maps, railroad maps, aeronautical charts, etc. Military maps are classified generally according to scale:

(*a*) *Small.*—Maps of small scale varying from 1:1,000,000 to 1:7,000,000 are needed for general planning and for strategical studies by the commanders of large units. Various types of general maps are employed for these purposes.

(*b*) *Intermediate.*—Maps of intermediate scale, normally from 1:200,000 to 1:500,000, are required for planning operations, including movement, concentration, and supply of troops. The Strategic Map of the United States, 1:500,000, is designed for these uses.

(*c*) *Medium.*—Maps of medium scale, normally from 1:50,000 to 1:125,000, are needed for strategical, tactical, and administrative studies by units ranging in size from the corps to the regiment. The United States Geological Survey map, scale 1:62,500, with wooded areas and road classifications added, has been found suitable for these purposes. This scale is used by the War Department for map production in strategic areas. While not suitable for all purposes, the scale of 1:62,500 has been found to be most advantageous for recording topographic detail for future use. During campaign, these maps may be used at this scale or they may be enlarged or reduced according to existing needs.

(*d*) *Large.*—Maps of large scale, normally not greater than 1:20,000, are intended for the tactical and technical needs of the Field Artillery and of the Infantry. The battle map or map substitute will be furnished for these purposes.

(2) *Overprints.*—Any of the foregoing maps may be used for overprints. An overprint is placed on existing maps and consists of needed information of special military value which may be shown in one or more colors: friendly positions, etc., in blue; enemy positions, etc., in red. For lithographic overprints in several colors, the draftsman is required to make a separate drawing for each color. This is usually done on tracing paper or tracing cloth in black ink.

(3) *Overlays.*—Overlays are transparent sheets giving special military information not ordinarily shown on maps. When laid over the map on which it is based, the detail on the transparent overlay, usually lithographed, will match corresponding details on the base map so that both may be seen at one time. The draftsman must normally make a tracing of each overlay or, if the overlay is printed in colors, a tracing for each color.

44. Photographs furnished.—*a. Engineer duties.*—The engineers engaged in mapping are furnished by the Air Corps with developed negatives and a limited number of copies of contact prints. The Corps of Engineers is charged with the following duties in connection with aerial photographs (par. 7, AR 300-15):

(1) *Mapping photographs.*—(*a*) Indexing of mapping negatives.

(*b*) Making of rectified prints when required.

(2) *General photography.*—(*a*) When directed by proper authority, with quantity lithographic reproduction and distribution of aerial photographs.

(*b*) Quantity reproduction and distribution of contact prints as may be reproduced by the rapid multiple-contact printer.

b. Duties of Air Corps.—The Air Corps is responsible for (par. 12, AR 300-15)—

(1) *Mapping photography.*—(*a*) Photography in accordance with specifications prepared by the Corps of Engineers.

(*b*) Processing of negatives.

(*c*) Marking of negatives for ready identification and filing them.

(*d*) Furnishing required prints to the Corps of Engineers.

(2) *General and intelligence photography.*—(*a*) Marking of negatives in accordance with FM 30-21.

(*b*) Making of limited numbers of prints.

(*c*) Storing and filing of negatives.

(*d*) When directed by proper authority, the preparation in field laboratories of uncontrolled mosaics of not to exceed ten prints.

(*e*) When engineer facilities are not available, the preparation in base laboratories of such uncontrolled mosaics as may be required by higher authority.

c. Request for photographs.—Ordinarily all requests for aerial photography to be performed by the Air Corps will be submitted through proper channels and should include the following information:

(1) Maps (flight diagram in triplicate showing area to be photographed).

(2) Photographs (size desired).

(3) Camera (type, single lens, 5-lens, etc.).

(4) Scale.

(5) Overlap—forward, side, desired angle of crab.

(6) Prints, number desired and kind (glossy or matte, single or double weight, trimmed or untrimmed, etc.); negatives, if desired.

(7) Project elevation—mean elevation of area to be photographed (if not clearly shown on map).

(8) Period during which work is to be accomplished.

(9) Request for any essential data, as focal length and flight attitude.

(10) A statement that no aerial photographs exist for the area in question or that the existing ones are unsuitable. In the latter case the reasons for the unsuitability of existing aerial photographs will be given.

NOTE.—A few words of explanation on some of the items in *c* above follow their corresponding numbers. (1) See paragraph 69. Usually a medium scale map serves best for this purpose. (2) The 9- by 9-inch is the best single lens size for general use. (4) The representative fraction will be given. (5) The overlaps for single lens photographs are usually 60 percent forward and 30 percent sideways, except that in very rugged terrain more side lap may be needed to insure coverage. No crab is desired for single lens, though about 5° to 10° is sometimes helpful with multiple lens photographs. (6) Unglazed, glossy prints show fine details more clearly, but they do not take pencil or ink readily. In any case, prints should be dried without any application of heat or pressure, which might cause paper distortion. Passing thoroughly dry prints through a straightener is not objectionable. (7) The mean elevation of the area should be given. (8) Due allowance should be made for weather unfavorable for photography.

45. Polyconic projection.—Standard quadrangle maps, battle maps, and other large-scale maps of the United States will be based on the polyconic system of projection. In other theaters of operation the projection will be prescribed by the chief engineer of the theater.

46. Grid system.—For a definite, brief description of points on military maps covering the United States, a system of rectangular coordinates, called the "Grid System for Progressive Maps of the

United States," has been adopted. For a complete description, etc., of this grid system, also known as "military grid," see paragraph 61 and AR 300-15.

47. Atlas grid.—The military grid is not applicable for map substitutes, due to inherent distortions, variations in scale, and the resultant difficulty in accurately locating the military grid lines thereon. A suitable atlas grid will therefore be applied to photographs, uncontrolled photomaps, provisional maps, and to maps whose accuracy does not warrant the use of the military grid. Applying the atlas grid to the map, the grid line will be lettered from left to right and numbered from bottom to top. The purpose of the atlas grid is to facilitate description and identification of points of interest. The grid lines will be equally spaced and approximately 1.8 inches apart. Starting at the left edge of the sheet, the vertical grid lines will be assigned letters A, B, C, D, etc., and from the bottom of the sheet the horizontal grid lines will be numbered 1, 2, 3, 4, etc. Thus the origin of decimal coordinates will be A.0-1.0 and the center of the nearest grid square will be A.5-15. On single verticals used for map substitutes, the grid numbers and letters, with ticks only, will be applied. On controlled mosaics, the approved military grid system will be applied as accurately as possible.

48. Marginal data.—*a. Maps.*—Refer to figure 88 for corresponding numbers encircled:

(1) Descriptive title and name, with location by State and county ①, index map number ②, etc. (For map index see geographic index, AR 300-15.)

(2) Representative fraction ③; graphical scale in yards and miles printed both with and against the grain of the paper to permit compensation for paper distortion.

(3) True meridian; magnetic meridian with annual variation from true north, showing date and annual change, with convergence in degrees and mils; grid *y*-axis with convergence in degrees and mils ④.

(4) Explanation of any symbol used which is not prescribed in FM 21-30 ⑤.

(5) Contour interval ⑥.

(6) Names of organizations responsible for control, topography, drafting, photography, and reproduction (if copies) with dates; date of revisions, if any ⑦.

(7) Projection used ⑧.

(8) Horizontal ⑨ and vertical ⑩ data.

(9) Diagram or statement of the control on which the map is based, together with a reference to published descriptions of same ⑪.

(10) Zone or zones of the military grid ⑫.

(11) Designations of geographic grid lines ⑬.

(12) Designations of military grid lines ⑭.

(13) Names and index of adjoining map sheets ⑮.

b. Photomaps.—(1) Descriptive title and key number.

(2) Approximate scale, graphically, in yards and by representative fraction.

(3) Date and hour of photography.

(4) Approximately true north or, if known, magnetic north.

(5) Direction of flight on verticals and composites.

(6) Approximate grid coordinates of center, when available.

(7) Designation of atlas grid lines or military grid lines when available.

(8) Contours or form lines when conditions warrant.

(9) When appropriate, a diagram or statement of any control used, together with a reference to published descriptions thereof.

(10) Names of important terrain features, such as towns, streams, mountains, highways, etc., will be added to photomaps which are to be reproduced in quantity.

49. Size of maps.—As far as practicable, all maps or photomaps of the same type will be of uniform scale, size, and make-up.

50. Contour interval.—On contoured maps, ordinarily those to a scale of 1:62,500 and larger, the contour interval will show the maximum delineation of the ground consistent with clearness and the most suitable method of preparation. For maps of hostile territory, with limited control available, the contour interval would usually be 50 feet or more. On maps produced in peacetime a smaller contour interval, say, 20 feet for 1:20,000 maps, 10 feet for 1:10,000 maps, etc., may be expected. (For specific directions see AR 300-15.)

51. Monuments and bench marks.—The position of all geodetic monuments and all other permanently established monuments and bench marks (preferably with their military grid coordinates) should be shown on all maps, and all photomaps when practicable. All secondary control points established by field parties, whether monumented or not, should be recorded, preferably by written description and diagram kept in a special file to permit their ready recovery, if needed for use by the artillery or in a later revision of maps.

52. Conventional signs.—Conventional signs will conform to those prescribed in FM 21-30.

53. Care and disposition of originals.—*a. Folding.*—Originals of maps and sketches whether drawings or tracings must never be folded. They should be kept flat at all times except when they are to be transported, or in an emergency when they may be rolled and kept in metal tubes.

b. Filing.—(1) Originals of maps together with all records pertaining to them prepared by troops in the field within corps areas or departments, and those on hand at stations which may be abandoned, will be filed in the office of the corps area or department engineer.

(2) Originals of maps and their records prepared by troops in the field outside corps areas or departments will be filed in the office of the chief engineer of the unit under which the troops operate, and on the discontinuance of such unit or expedition will be filed in the office of The Adjutant General.

Section X

PROFILES AND CROSS SECTIONS

54. Profile and grade lines.—*a. General.*—A profile (fig. 114) is a line representing the surface of a piece of ground plotted from certain data obtained from observations or measurements by field parties or from large scale contour maps. Profiles are made for the center line of roads and railroads to be constructed; for other military projects; and as one of the methods for determining the intervisibility between two points on a map. (See FM 21-30.)

b. Plotting a profile.—(1) The profile is plotted on special paper, the vertical scale being exaggerated. In road and railroad profiles the scales used may be 400 feet to the inch horizontally and 20 feet to the inch vertically. A still greater exaggeration is generally used in drainage profiles.

(2) The first step is to decide from an examination of the range of the elevations where to start the drawing on the paper so that it will be centrally located on the paper and will fall within the limits of the sheet. Station 0+00 of the profile should come on one of the heavy vertical lines, and the heavy horizontal lines should represent elevations such as 100, 110, 120, etc.

(3) The profile is drawn in pencil first, using the rulings of the profile paper as a scale, and afterward inked in. Check all surface elevations by reading from the profile station and elevation of each point as plotted and comparing them with the original data. Com-

plete the profile by inking in all lines and figures and put on a title containing such information as necessary. The completed profile should be similar to the one in figure 114 without the grade line. Figure 113 represents profile notes corresponding to the profile plotted in figure 114.

c. *Drawing grade lines.*—The drawing of grade lines is usually the concluding part of profile plotting. After making the profile, the grade line is established by stretching a fine thread through the ruling points, allowing for smooth vertical curves, taking into account the controlling conditions, such as maximum gradient or earthwork quantities on a railroad profile, the carrying capacity or the scour in case of a ditch, etc. After laying the grade line on the profile, notes are made of the data, as shown in figure 116, a set of field notes partially prepared from office data and used in the field for cross-section work. See paragraph 55.

d. *Exercise No. 18: profile and grade line.*—From notes supplied by a field party (similar to fig. 113), draw the profile and grade line on profile paper (either drawing or tracing paper) similar to that shown in figure 114, indicating the maximum grade. The amount of cut (−) or fill (+) is shown for every 100 feet of horizontal distance along the profile as illustrated in the figure. This amount is equal to the difference in elevation between the profile and grade line at that particular point. If the profile is lower than the grade line the amount is plus (+), if higher it is minus (−). Complete the sheet after inking all lines and numerals by adding an approximate title and, if necessary, a legend for additional information.

55. Cross sections.—*a. General.*—(1) Cross sections (fig. 117) are used to determine the amount of earth to be moved to bring the ground to the proper grade. These cross sections are plotted after the field party obtains the necessary data (4th column, fig. 116) and returns them to the drafting room.

(2) Cross sections are usually drawn in pencil on heavy cross section paper subdivided equally in both horizontal and vertical directions, usually 10 to the inch.

(3) Each cross section is identified by a number which expresses the distance from the zero station of the profile line as 0+50, 1+00, 1+50, etc. Figure 117 shows a completed cross section plot.

(4) Figure 115 is a portion of a topographical map showing mountainous terrain and a section of same along the line *AB*. In the section the 100-foot map contour interval along the line *AB*, together with their intersections of the lines designating differences

Leveler: Sgt. H.L. Chippeaux — Rodman: Sgt. C.F. Browning — Dumpy Level #12328 — (11)

PROFILE LEVELS FOR ROAD FROM ○0+00 TO ○11+00

Sta.	+ B.S.	H.I.	− F.S.	Elev.	Elev. T.P.	Remarks: Nov. 16, 1939 (2¾ hours) Fair, windy
0+00	0.06	123.56			123.50	Wooden peg
0+00			0.4	123.2		
1+00			6.3	117.3		
T.P.	0.32	111.35	12.53		111.03	
2+00			5.4	106.0		
2+56			9.7	101.7		Center stream bed 5' wide 2½' deep
2+56	3.91	105.93	9.33		102.02	T.P.
3+00			4.5	101.4		
3+90			6.7	99.2		Center stream bed 5' wide 2½' deep
4+00			4.5	101.4		
4+27			2.7	103.2		Bottom steep slope
T.P.	13.00	118.51	0.42		105.51	
4+80			2.8	115.7		Top steep slope
5+00			1.2	117.3		
5+00	8.24	125.95	0.80		117.71	T.P.
6+00			4.8	121.2		
7+00			2.9	123.1		S. edge ser. rd. N. old hos.
7+00	5.32	128.86	2.41		123.54	T.P.
8+00			4.7	124.2		℄ existing mac. rd. off center entrance
9+00			3.4	125.5		old hos. 7+00 8+00
10+00			4.6	124.3		℄ S. edge ser. rd. N. old hos.
10+00	0.88	125.46	4.28		124.58	T.P. 10+70 11+00
10+70			3.8	121.7		Top of slope 11+70
11+00			6.4	119.1		
						Checked: Sgt Bedell

Leveler: Sgt. H.L. Chippeaux — Rodman: Sgt. C.F. Browning — Dumpy Level #12328 — (12)

PROFILE LEVELS FOR ROAD FROM ○T.P. TO ○19+00

Sta.	+ B.S.	H.I.	− F.S.	Elev.	Elev. T.P.	Remarks: Nov. 16, 1939 (2½ hours) Fair, windy
T.P.	0.26	113.15	12.57		112.89	
11+70			6.3	106.9		Bottom of slope
12+00			9.3	103.9		
12+00	0.73	104.93	8.95		104.20	T.P.
13+00			4.7	100.2		S. edge of old r.r. rt. of way
13+24			9.5	95.4		Bottom of stream bed 15' wide 5' deep
14+00			6.7	98.2		13+00 14+00
14+60			6.9	98.0		13+24
14+60	1.70	100.18	6.45		98.48	T.P. Change of direction
15+00			5.7	94.5		
T.P.	8.27	98.57	9.88		90.30	
15+59			12.0	86.6		N. bank of stream 8' deep
15+84			10.0	88.6		S. bank of stream 8' deep
16+00			8.8	89.8		Bottom of slope
T.P.	11.80	110.06	0.31		98.26	
T.P.	12.54	121.98	0.62		109.44	
17+00			7.9	114.1		
T.P.	10.71	132.56	0.13		121.85	
17+42			9.1	123.5		Top of slope
18+00			7.0	125.6		
19+00			1.00		131.56	N. edge of old ser. rd.
	77.74		69.68		123.50	
			77.74		8.06	
			8.06			
						Checked: Sgt Bedell

FIGURE 113.—Profile notes.

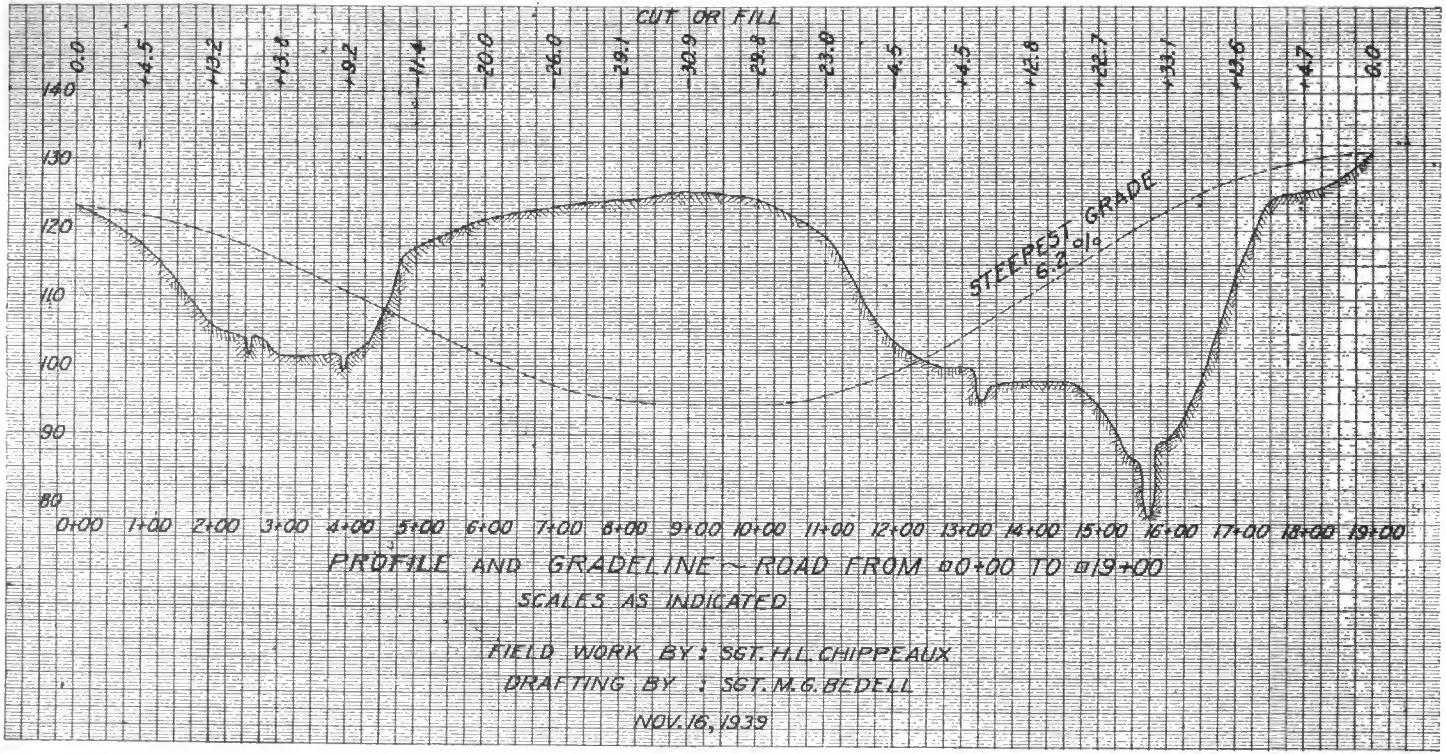
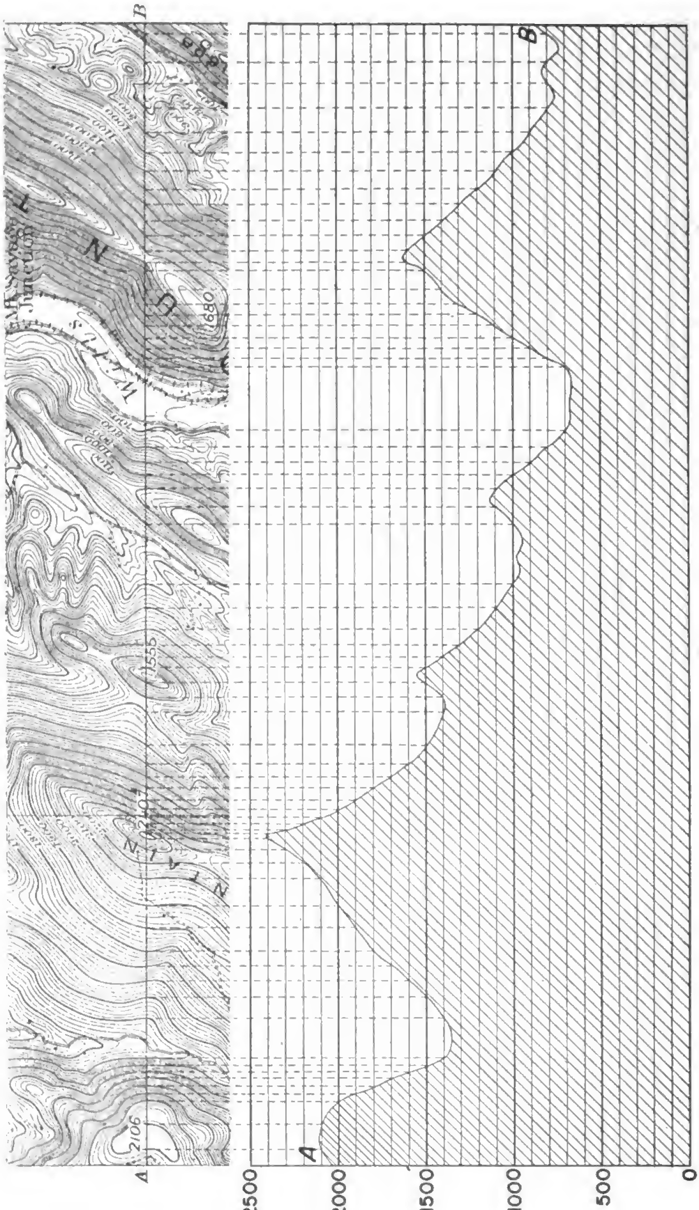


FIGURE 114.—Profile and grade line (exercise No. 18).

of elevations, is used to obtain the profile which is represented by the irregular line.



AREA OF MARKED RELIEF PART OF FROSTBURG (MD.-W. VA.-PA.) SHEET, WITH SECTION ON LINE A-B

FIGURE 115.—Cross section from topographic map (exercise No. 19).

b. Exercise No. 19: cross section from topographical map.—(1) Draw a cross section along a line *CD* parallel to and ½ mile north

of the line AB to the horizontal scale 1:20,000, similar to the one in figure 115, using the 1:62,500 map in figure 115.

(2) First draw a line CD parallel to and ½ mile north of the line AB on the map in figure 115.

(3) On a piece of profile paper large enough to accommodate the cross section, enlarged to 1:20,000, indicate and draw the zero elevation line. By inspection of the 1:62,500 map along the line CD determine the highest elevation. Assuming a vertical scale of ¼ inch=100 feet, mark at the left end of the zero elevation line every 100-foot elevation interval crossing the line CD, up to the nearest 100 feet above the highest elevation.

(4) Using proportional dividers set at the ratio of $\frac{20{,}000}{62{,}500}=8/25$, lay off along the zero elevation line the distances between 100-foot contours, measured along the line CD from the 1:62,500 map, to the required 1:20,000 scale. From each of these marks draw a fine vertical line to the horizontal line representing its elevation. Connect the upper ends of these vertical lines with a smooth, unbroken curved line. This line represents the profile of the ground along the line CD on the 1:62,500 map to the scale of 1:20,000. Complete the cross section similar to the one shown in figure 115, adding title and other marginal information as required.

c. *Exercise No. 20: cross section for road.*—From a set of notes similar to those in figure 116 plot the cross sections for a road as shown in figure 117. Draw each cross section separately, beginning with the first one (usually numbered 0+00) and continue until completed. Cross sections are plotted to obtain the areas of cut and fill for computing earth quantities. To do this the undisturbed ground line and the finished ground line for each section must be plotted. Assuming a convenient base elevation, marked on one of the heavy horizontal lines of the cross section paper, which should be large enough to accommodate all the cross sections for one project, draw first the finished grade-line and slope lines and then the undisturbed ground line. The slope lines represent the bank (if any) on each side of the road, the ratio of the slope of these banks having been predetermined and made known to the draftsman. Number each section and add all marginal information as required.

d. *Earthwork computations.*—To calculate the quantities of earth to be moved, first, the area of each cross section must be obtained by dividing the area into triangles and adding the separate values of their areas, or the area of each cross section is obtained by the use of the planimeter. The latter is the more practical method espe-

cially when the sections are irregular. The areas, as obtained from planimeter readings, are tabulated as shown in figure 118, keeping "cut and fill" separate. The volume then is computed from the areas of the cross section. The simplest method of doing this is to average the areas of each two adjacent sections and multiply by the distance between them, i. e.,

$$V=\left(\frac{A_1+A_2}{2}\right)\times l \text{ (end area formula)}$$

in which A_1 and A_2 are the areas of the two sections and l the distance between them. This method is used very extensively although

CROSS-SECTION FOR MT. VERNON R.R.						Instrument: Birch Rod: Oakes, Steele	Level: Berger #3571 Date: Jan. 4, 1940 (27)
	Surface Elev	Grade Elev	Cross-Sections Base 40 – Slope 1½ to 1				
0+50	151.5	150.7	29.0 / -6.0	-0.8	22.4 / -1.6		
1+00	151.0	150.1	27.2 / -4.8	-0.9	24.0 / -3.3		
1+50	150.6	149.4	26.0 / -4.2	-1.2	25.5 / -3.7		
2+00	150.1	148.7	25.1 / -3.6	-1.4	22.5 / -1.6		
2+50	149.4	148.0	25.1 / -3.5	-1.4	22.4 / -1.5		
3+00	149.2	147.3	24.8 / -3.2	-1.9	22.0 / -1.4		
3+50	149.0	146.6	24.5 / -2.9	-2.4	21.8 / -1.3		
4+00	148.8	145.9	23.9 / -1.4	-2.9	21.7 / -1.2		
4+50	147.2	145.2	23.0 / -1.5	-2.0	21.5 / -1.0		
							Checked: Sgt. Bedell

FIGURE 116.—Cross section notes.

it does not give sufficiently accurate results for certain classes of work. A more nearly correct value may be determined by using the prismoidal formula:

$$V=\tfrac{1}{6}(A_1+4A^m+A_2)\times l,$$

in which l is the distance between the areas of the two end sections A_1 and A_2, and A^m is the "middle area," the area halfway between the two end sections. Three adjacent sections are taken, A_1 and A_2 being the first and third, respectively, and A^m being the second. It

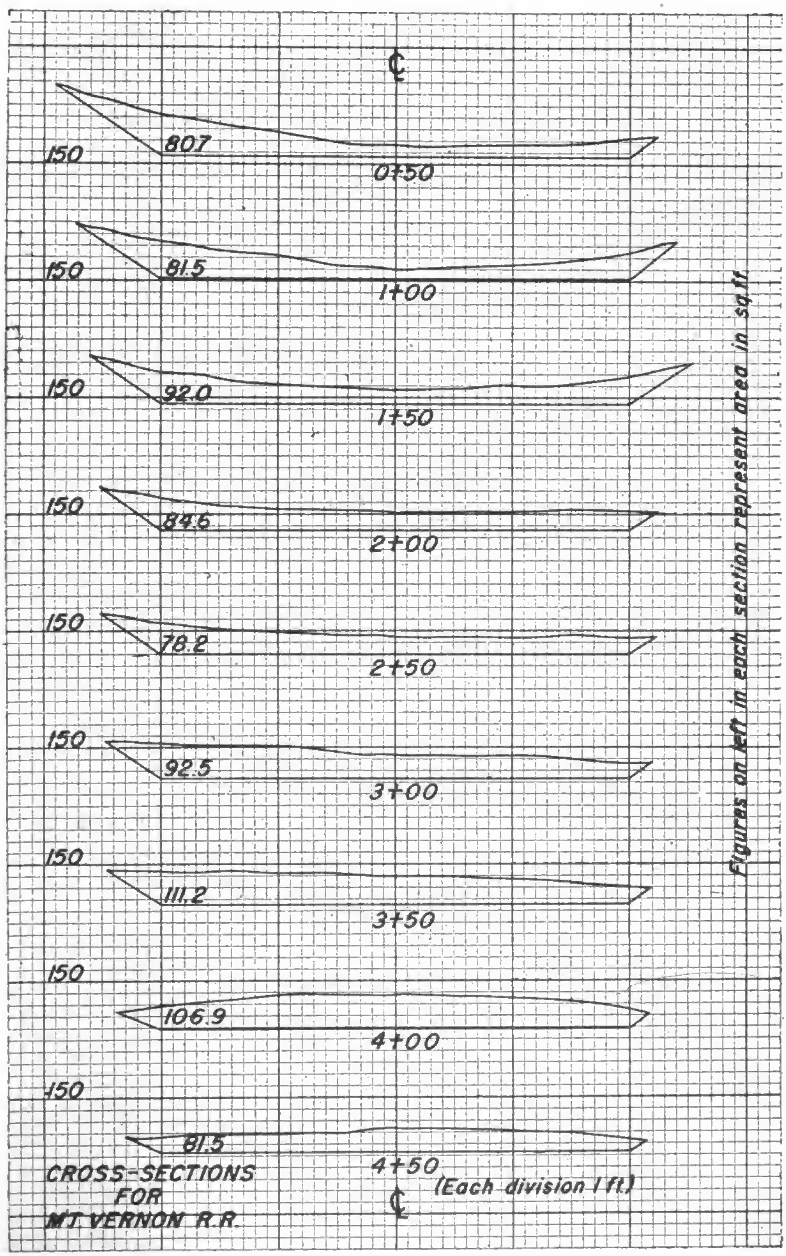


FIGURE 117.—Cross section for road (exercise No. 20).

is evident from this that the area of every alternate section becomes a "middle area." The total volume of earth to be moved is obtained by adding separately all cuts and all fills, converting, if necessary, each total into cubic yards.

e. Cross sections for grading areas, etc.—See TM 5–235.

CROSS-SECTION FOR MT. VERNON R.R. — Instrument: Birch; Rod: Oakes, Steele — Level: Berger #3571; Date: Jan. 4, 1940 — 27

	Surface Elev	Grade Elev	Cross-Sections Base 40' - Slope 1½ to 1			Area of Section in sq ft	CUT	FILL	Remarks
0 + 50	151.5	150.7	29.0 / -6.0	-0.8	22.4 / -1.6	80.7	4035.0	———	No excavation at 0 + 00 Figures for cut and fill are cu. ft
1 + 00	151.0	150.1	27.2 / -4.8	-0.9	24.0 / -3.3	81.5	4075.0	———	
1 + 50	150.6	149.4	26.0 / -4.2	-1.2	25.5 / -3.7	92.0	4600.0	———	
2 + 00	150.1	148.7	25.1 / -3.6	-1.4	22.5 / -1.6	84.6	4230.0	———	
2 + 50	149.4	148.0	25.1 / -3.5	-1.4	22.4 / -1.5	78.2	3910.0	———	
3 + 00	149.2	147.3	24.8 / -3.2	-1.9	22.0 / -1.4	92.5	4625.0	———	
3 + 50	149.0	146.6	24.5 / -2.9	-2.4	21.8 / -1.3	111.2	5560.0	———	
4 + 00	148.8	145.9	23.9 / -1.4	-2.9	21.7 / -1.2	106.0	5030.0	———	
4 + 50	147.2	145.2	23.0 / -1.5	-2.0	21.5 / -1.0	81.5	4075.0	———	
							40140.0		
								Checked:	Sgt Bedell

FIGURE 118.—Earthwork computation from cross-section notes.

SECTION XI

MAP PROJECTIONS AND COORDINATES

56. General.—*a. Definition.*—A map is a representation of a portion of the earth's surface on a convenient scale to show the relative points and natural features of the earth. The map is usually a plane or flat surface, while the surface of the earth is in the shape of a spheroid. Certain difficulties are therefore met in representing a

portion of the earth's surface, reduced in scale, upon a flat sheet of paper. The means by which this is done is called "projection."

b. Scope.—While it is not within the scope of this manual to explain the mathematical principles involved, a brief discussion of the more commonly used projections is included. For a detailed discussion of map projection, including the mathematical solutions, reference is made to Special Publication No. 68, Elements of Map Projection, U. S. Coast and Geodetic Survey.

c. Requirements.—(1) There are various properties desirable in a map:

(*a*) It should represent areas in their true shape.

(*b*) The areas represented should retain their relative size on the map.

(*c*) The distance of each place from every other should bear a constant ratio to the true distance upon the earth.

(*d*) The geographic latitudes and longitudes (par. 57) of the places should be easily found from their positions on the maps, and, conversely, positions should be easily plotted on the map when their latitudes and longitudes are given.

(2) These properties could easily be secured if the earth's surface were a plane or a surface that could be developed into a plane. A spherical surface, however, cannot be developed into a plane without distortion of some kind. It becomes, then, a matter of selecting the most desirable of the properties enumerated above. The purpose that the map is to fulfill must be carefully considered and that projection selected which comes nearest to supplying the requirements.

d. Projections.—Projections may be classified as follows:

(1) Equal area projections, which keep the areas directly comparable all over the map at the expense of the correct shape.

(2) Conformal projections, which keep the shape of the smaller geographical features correct at the expense of a changing scale all over the map, and which show all meridians and parallels at right angles without preserving the shape of the larger geographic features.

(3) Azimuthal projections (sometimes incorrectly called zenithal projections), which preserve the correct directions of all lines drawn from the center of the map to give correct azimuths. These are important for water and air navigation.

(4) Perspective or geometric projections, which consist of the direct projection of the points of the earth by straight lines drawn through them from some given point. The projection is generally made upon a plane tangent to the sphere at the end of the diameter joining the point of projection and the center of the earth.

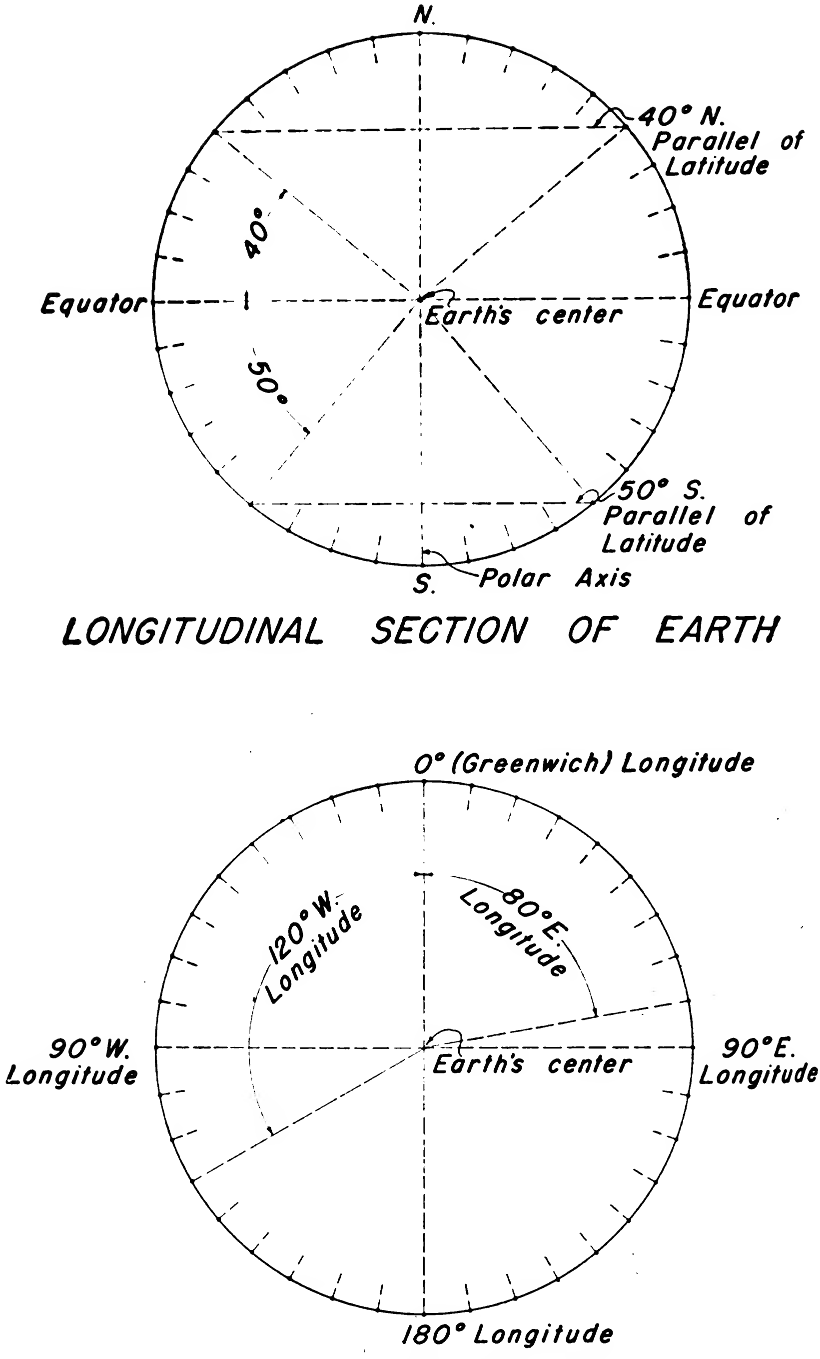


FIGURE 119.—Derivation of latitude and longitude.

(5) Conventional projections, which compromise between the various conditions stated above.

57. Latitude and longitude.—Latitude and longitude, also called "geographic coordinates" and "spherical coordinates," are an assumed net of lines running true east and west (parallels of latitudes) and true north and south (meridians of longitude). Visualizing the

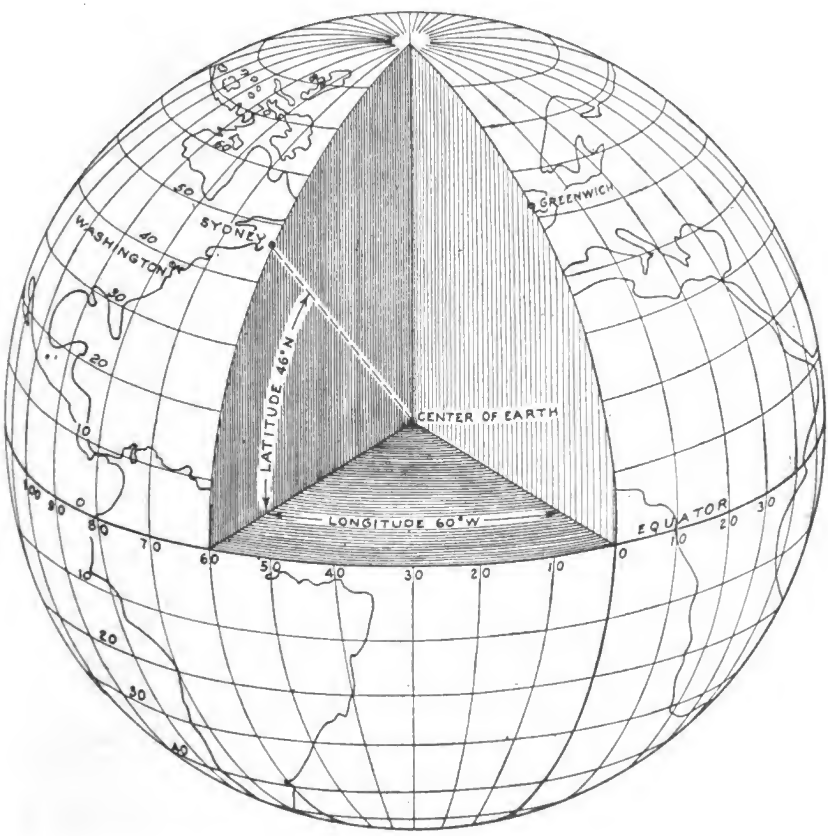


FIGURE 120.—Measuring latitude and longitude of point on earth's surface.

center of the earth as the intersection of the polar axis with the center of the equatorial plane, the latitude of any point on the earth's surface for all practical purposes may be said to equal the angle subtended between the equatorial plane and the line from that point to the center of the earth. (See figs. 119 and 120.) Points north of the equatorial plane are in latitude N. (north) so many degrees, etc.,

all latitudes being between 0° and 90°. The longitude of any point on the earth's surface is equal to the angle subtended by the plane of the zero meridian (the shortest line on the earth's surface connecting the South Pole and North Pole and passing through Greenwich, England), and the meridian plane of the place, the vertex of the angle being at the earth's polar axis. Points to the west of the zero (or

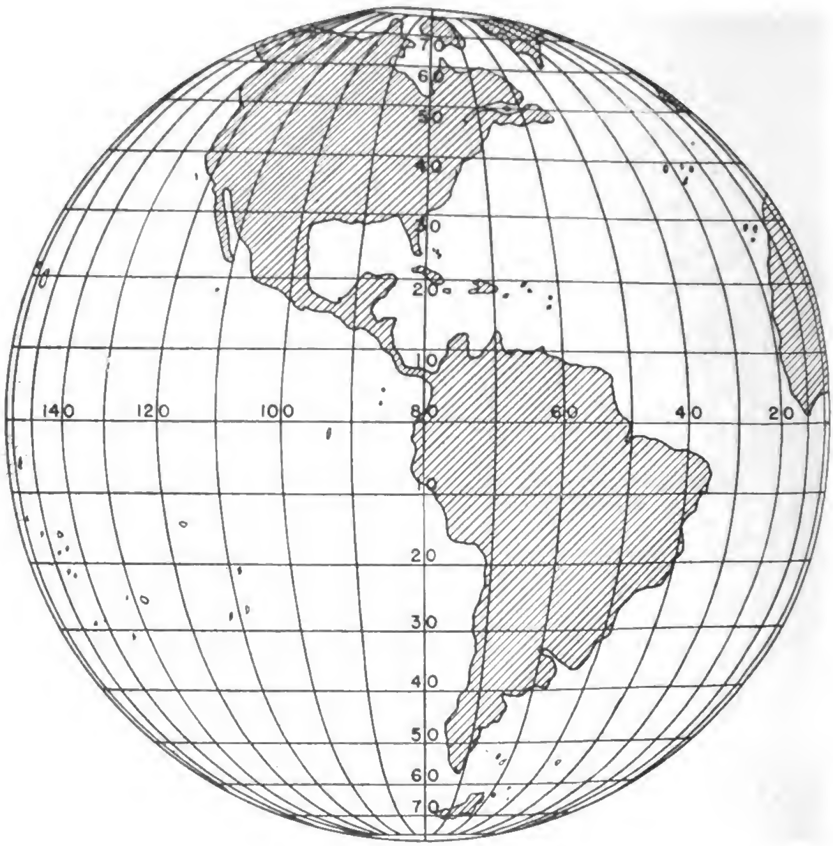


FIGURE 121.—Orthographic projection.

Greenwich) meridian are in longitude W. (west), and points to the east in longitude E. (east), none exceeding 180° in either direction. The angle latitude 46° N. (fig. 120) indicates how the latitude of a place on the earth's surface is measured; the angle longitude 60° W. in the same figure indicates how the longitude of a place on the earth's surface is measured.

58. Map projections.—*a. Types.*—Of the more common projections, only four—the orthographic, Mercator, conic, and polyconic—

are described here. The polyconic being used more than any other for map making in the United States, is explained in detail in paragraph 59.

b. Orthographic projection.—This projection (fig. 121) is used to show objects in plan, front and side elevation, on architectural and engineering drawings. In map making this projection is rarely used when representing the two hemispheres as it contracts distances too much between points near their edges.

c. Mercator projection.—The Mercator projection (fig. 122) is constructed by projecting the meridians and parallels onto the surface

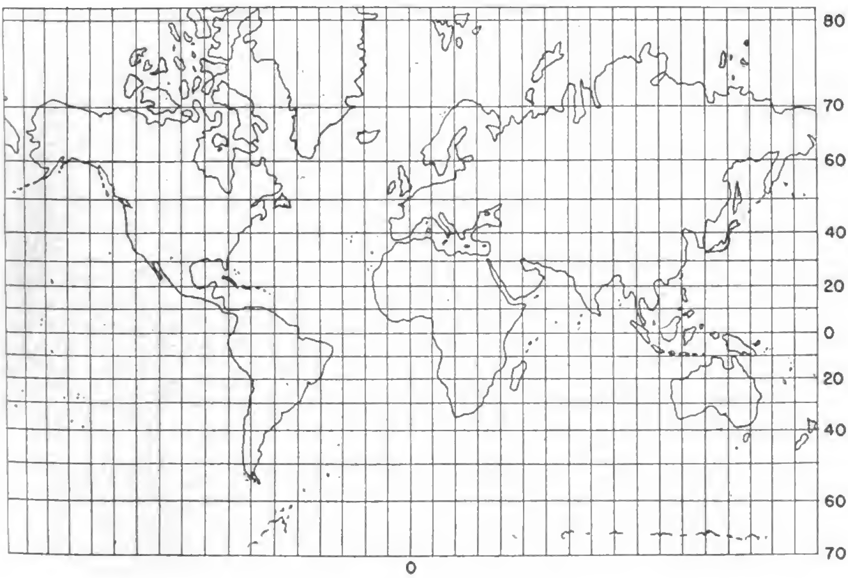
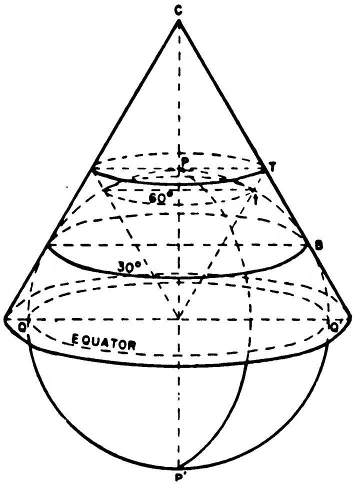


FIGURE 122.—Mercator projection.

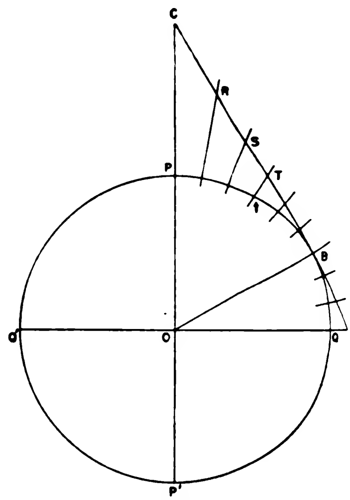
of a cylinder which is tangent to the earth at the Equator, and then developing this cylinder on the map. The meridians and parallels all appear as straight lines, meridians being equally spaced while the distances between parallels increase toward the poles. The Mercator chart is much used in navigation, as the bearing between any two points as shown by this chart is the course a vessel would have to steer to get to his destination by the shortest possible route.

d. Conic projection.—In the conic projection (fig. 123) a cone is assumed to be tangent to the middle parallel of the map, the apex of the cone lying in the prolongation of the earth's axis. The cone is developed by first drawing a vertical line as the central meridian of the map. Selecting a suitable point on this line, the radius of the mid-

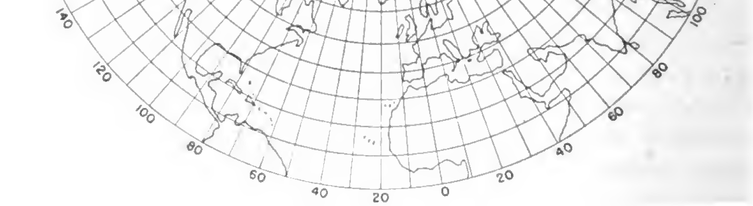
dle parallel of latitude is then laid off on the side toward the pole, thus locating the apex of the cone which serves as the center of a series of circles representing the parallels of latitude. The latter are drawn



① Cone tangent to earth at latitude 30°. *B* is point of tangency of cone on parallel of latitude 30°. *QQ'* is the Equator distorted in the projection as indicated by circle marked "Equator"; a similar distortion occurs at latitude 60°.



② Determination of radii for a conic projection. *PQP'Q'* is a meridian circle; *CB* is a tangent to same at latitude 30°. The quadrant *PQ* is divided into 10° intervals. *CR, CS, CT,* etc., are radii for the parallels of 80°, 70°, 60°, etc., respectively, and so used in the projection below.



③ Conic projection on cone tangent at latitude 30°.

FIGURE 123.—Illustrating theory of conic projection.

through points, corresponding to proportional intervals of latitude, previously laid off on the central meridian. After subdividing the middle parallel to correspond to proportional intervals of longitude,

straight lines representing meridians are drawn from the apex of the cone to these subdivisions. The distortion in this projection is so small that it becomes apparent only on maps of very large areas.

59. Polyconic projection.—*a.* The polyconic projection, as its name implies, is developed on a series of cones (fig. 124), a different cone being used for each parallel of latitude. This projection has been adopted by the U. S. Coast and Geodetic Survey and for nearly all other Government surveys. Special Publication No. 5, U. S. Coast and Geodetic Survey, contains tables giving all necessary data to be used in the construction of the polyconic projection.

b. Exercise No. 21: polyconic projection.—(1) Draw the polyconic projection of a 15-minute quadrangle at the scale of 1:40,000. Re-

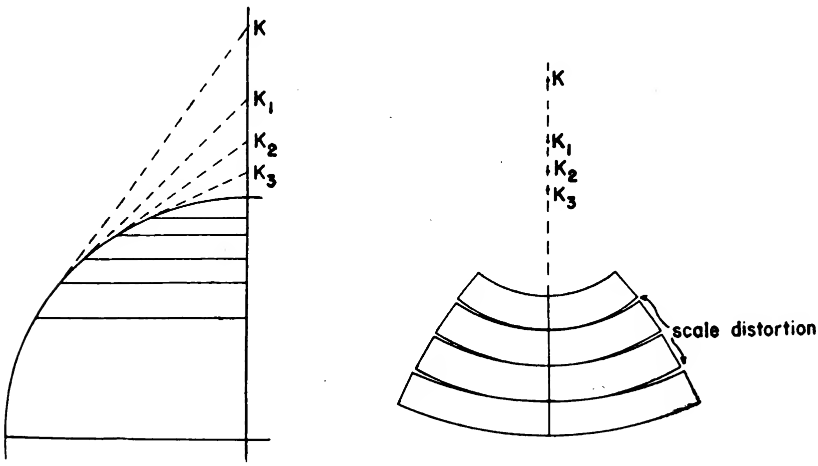


FIGURE 124.—Illustrating development of polyconic projection.

ferring to figure 126, make a rough working diagram of the projection and enter on it from the tables mentioned in *a* above all the dimensions that are needed. Check these data before using. Draw a straight dotted line for a central meridian and a construction line perpendicular thereto (*ab* in the figure), both lines to be as central to the sheet as the selected interval of latitude and longitude will permit.

(2) On the central meridian lay off the intervals of latitude, north and south (beginning with the intersection of line *ab* as initial point), using the distances given in the table, Special Publication No. 5, from the columns headed "Continuous sums of minutes, etc.," pages 11–189, odd numbered pages only.

(3) This establishes points m_0, m_1, m_2, and m_3 etc. Through m_0, m_2, and m_3 draw additional construction lines parallel to *ab;* mark

FIGURE 125.—Polyconic projection of the United States.

off for every border meridian to be represented the ordinates from the central meridian (east and west) taken from pages 11–189, Special Publication No. 5, subcolumn X under "Coordinates of curvature."

(4) At these points, which are the tentative four corners of the projection, lay off lines parallel to the central meridian, their length corresponding to the values of Y taken from the same table as X above. The end points of these lines are the intersections for the border meridians and border parallels of latitude of the projection. Draw lines connecting these points. Divide each border line into three equal parts and connect opposite marks for these parts by straight lines. These lines are the intermediate 5-minute meridians and parallels of latitude. Check the construction with the beam compass and finish the projection, as indicated in figure 126, with ink omitting all dotted or dashed lines.

(5) The above is a compromise method intended for use on the 1:40,000 scale. For a more detailed method of plotting this projection, especially for larger areas, follow carefully the instructions given on page 8, Special Publication No. 5, U. S. Coast and Geodetic Survey.

(6) Another method, described on pages 34 and 35, Bulletin 650, U. S. Geological Survey, may be used. This bulletin contains tables permitting the plotting of latitude and longitude intervals in inches on the map scales 1:12,000, 1:24,000, 1:48,000, 1:62,500, 1:63,360, and 1:125,000.

60. Rectangular coordinates.—*a.* Rectangular coordinates are distances from a fixed point, called the "origin," to any other point, such distances being measured along lines parallel with two lines intersecting at right angles at the origin, the two lines running south-north and west-east through the origin. Thus, when the positions of any number of points are given by their distances from a common origin, the distance and direction with respect to each other can be obtained by plotting or computing. The location of a point is always expressed by two values: the difference in latitude and the difference in longitude as measured from the origin, usually expressed in feet or yards. The difference in latitude is called "latitude" and the difference in longitude "departure." Assume that the rectangular coordinates of five different stations, A, B, C, D, and E, on a closed traverse, expressed in yards are as follows:

Station	*Latitude*	*Departure*
A	100, 000	100, 000
B	103, 000	102, 000
C	104, 000	105, 000
D	102, 000	106, 000
E	99, 000	104, 000

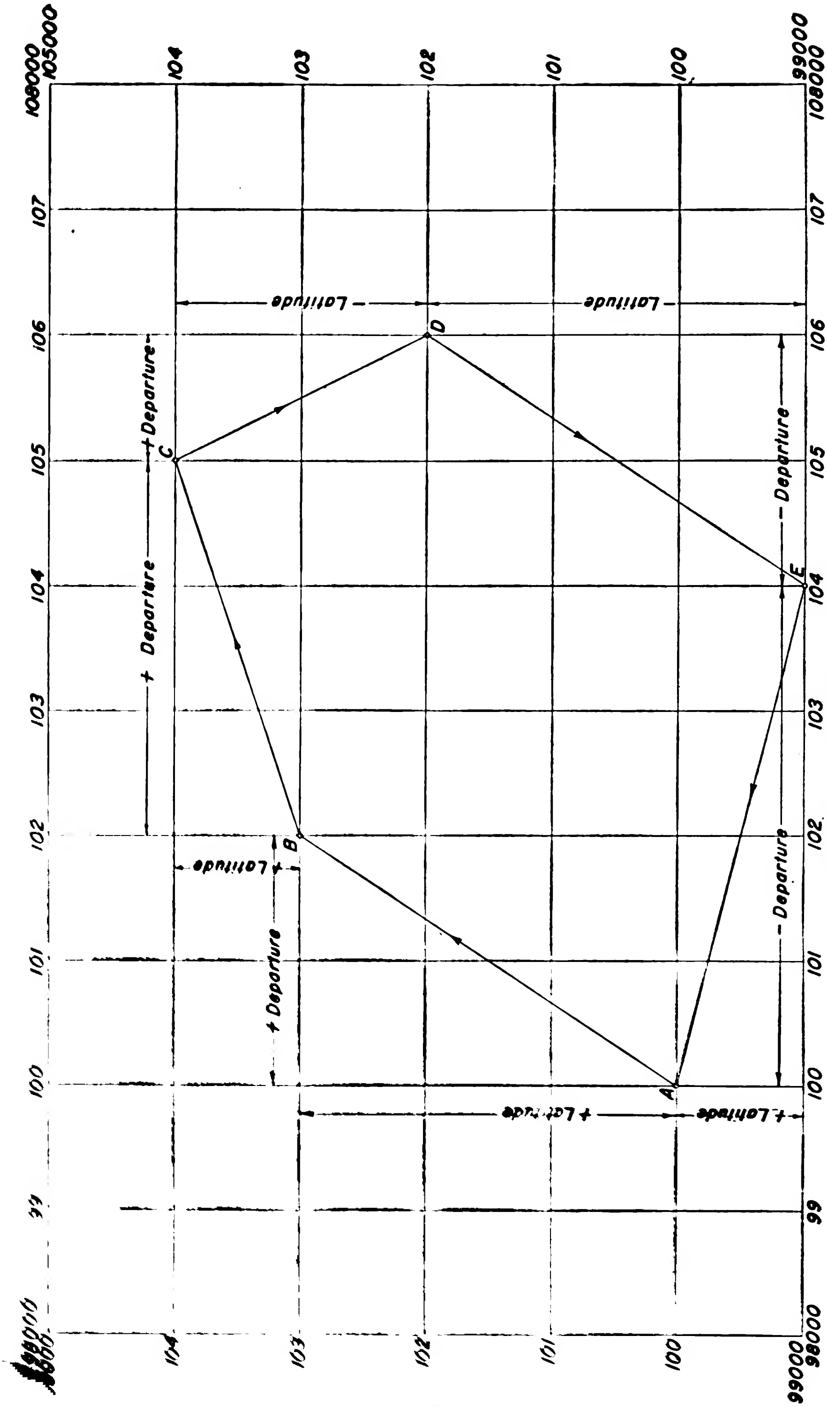


FIGURE 127.—Rectangular coordinates.

A, the origin, is assigned coordinates of 100,000 for both its latitude and departure to avoid the use of plus and minus signs. As shown in figure 127, in which the lines are 1,000 yards apart, A lies at the intersection of the 100,000 west-east and the 100,000 south-north line. Likewise, B, C, D, and E fall on lines parallel to A's 100,000 lines, viz, B at the intersection of the 103,000 west-east line and the 102,000 south-north line; C at the intersection of the 104,000 west-east line and the 105,000 south-north line; etc., etc.

b. The rectangular coordinates of a station are usually obtained from triangulation or traverse computations explained in TM 5-235.

61. Grid system of the United States.—*a. General.*—For military purposes it is necessary to have a system of lines on a map which is suitable for determining distances and directions between objects in a very short time. The only quick method is by a system of rectangular coordinates. A separate system of rectangular coordinates may be used to cover a small local area. This, however, would result in much confusion when it becomes necessary to join adjacent maps. In order to overcome this there has been adopted for the United States a simple system of rectangular coordinates, called grid coordinates. This system divides the United States into large zones extending over 9° of longitude from west to east and the entire latitudinal distance of the United States (fig. 128). There are seven such zones, A, B, C, D, E, F, and G, each of which overlaps 30 minutes in longitude into the adjacent west and east zones. The central and limiting meridians of the several zones are—

Zone	*Central meridian*	*Limiting meridians*
A	73°	68°30′– 77°30′
B	81°	76°30′– 85°30′
C	89°	84°30′– 93°30′
D	97°	92°30′–101°30′
E	105°	100°30′–109°30′
F	113°	108°30′–117°30′
G	121°	116°30′–125°30′

The intersection of each central meridian and the parallel of 40°30′ latitude is the initial point or origin of the grid system for each zone. To make all coordinates within each zone positive the central meridian (origin of y coordinates) is labeled with the arbitrary value of 1,000,000, and the parallel of 40°30′ latitude (origin of x coordinates) with the arbitrary value of 2,000,000. Extensions have been made in the case of zones A and D to cover the areas indicated in figure 128, which shows the grid zones covering the entire United States. Figure 129 shows the projection and grid coordinates of zone B.

FIGURE 128.—Grid zones for military maps of the United States.

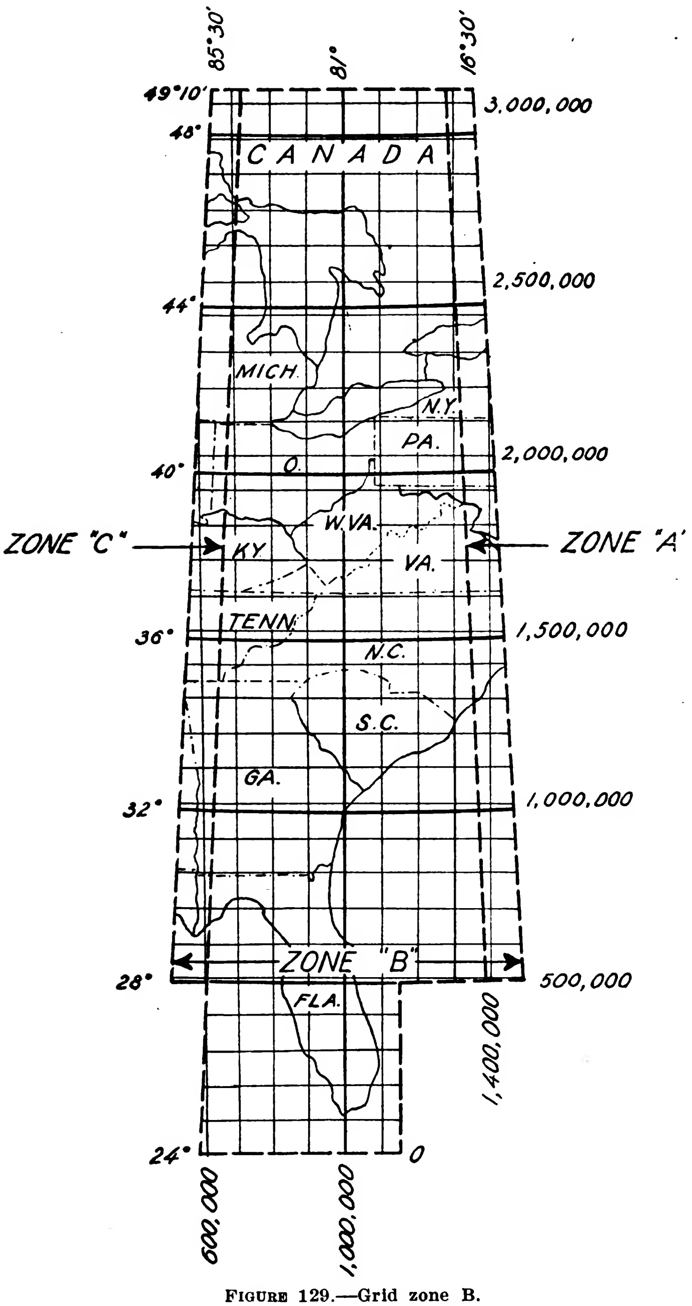


FIGURE 129.—Grid zone B.

b. Exercise No. 22: grid coordinates.—(1) Construct grid coordinates to the scale of 1=20,000, spaced 1,000 yards apart, on a sheet showing the area between lat. 38°40′ to 38°45′ and long. 77°05′ to 77°10′.

(2) Take out *x* and *y* values from the table (given in yards) in Special Publication No. 59, U. S. Coast and Geodetic Survey, for the four corner points, which are 5-minute intersections of meridians and parallels. The geographic coordinates of these points are—

Latitude	*Longitude*
38°45′	77°10′
38°45′	77°05′
38°40′	77°10′
38°40′	77°05′

(3) On page 134, Special Publication No. 59 (lines 8 and 9, respectively), are found the *x* and *y* values as marked in figure 130. Lines running south-north are determined from *x* values, lines running west-east from *y* values.

The *x* and *y* values should be penciled at or near their corresponding points on the drawing on which the coordinates are to be constructed or on a separate scratch diagram for ready reference.

(4) The *x* value in this case being greater than 1,000,000 indicates that the area covered is east of the central meridian of its grid zone (in this case, B zone, the central meridian of which is the 81st).

(5) It is always best to locate and draw first the four 1,000-yard grid lines nearest to the border inside the area, in this example the south-north grid lines 1365000 and 1372000, and the west-east grid lines 1795000 and 1786000. The most practical method by which this is accomplished is by drawing arcs from the four corners the radii of these arcs being equal to the difference between the coordinate values of the four lines to be drawn and the coordinate values of the corners obtained from the table, the latter penciled onto the sheet. To draw the arcs and lines proceed as follows: Beginning with point (1) take the difference between 1364330 and 1365000, or 670 yards, as a radius and describe an arc of a circle eastward, using the intersection of point (1) as a center. Continuing with point (3) take the difference between 1364754 and 1365000, or 246 yards, as a radius and describe an arc of a circle, also eastward. Next draw a straight line tangent to the arcs just drawn. This is the 1365000 south-north grid line.

(6) Proceed, drawing the 1372000 south-north grid line, using the difference between 1372246, point (2), and 1372000; and 1372678, point (4), and 1372000 as radii for arcs westward of points (2) and (4), respectively.

(7) Next draw the 1795000 west-east grid line using the difference between 1795147, point (1), and 1795000; and 1795483, point (2), and 1795000 as radii for arcs southward of point (1) and (2), respectively.

(8) In a similar manner determine the 1786000 west-east grid line.

(9) Next check the diagonals between the corners made by the intersections of the four grid lines just drawn and the length of these grid lines. The diagonals should be the same length and each side the same length (in exact multiples of the grid interval) as the opposite side; if not, some error in plotting has been made.

(10) Now divide the distance between the 1365000 and 1372000 south-north grid lines into the required number of equal parts and draw parallel lines for the intermediate south-north grid lines; likewise divide the distance between the 1786000 and 1795000 west-east grid lines; thus completing the construction of the grid.

(11) Label all grid lines and finish the sheet, including marginal data, as shown in figure 130, in ink, omitting dotted lines and numbers.

Section XII

OFFICE COMPUTATIONS AND ADJUSTMENTS

62. General.—Every draftsman must be familiar with office records relating to data on which military maps are based. These records include transcriptions from field and office computations, giving coordinates (both geographic and grid) of control stations; distances and azimuths between them; and their elevations. It is desirable that every draftsman receive sufficient training in mathematics to make and check computations. Subjects covered in this and the section following make it necessary for the draftsman to be conversant with mathematics including plane trigonometry; that he know certain terms and their definitions; and that he be acquainted with certain methods used by field parties. For a study of mathematics the student is referred to Special Text, Part VI, Mathematics, a concise text suitable for self-instruction, especially prepared for the surveying and drafting course given to enlisted specialists at the Engineer School, Fort Belvoir, Va. If this is not available, any

other standard text covering the subject may be used. For a study of field records and surveying computations, etc., consult the alphabetical index for the section or sections in TM 5–235, which explain the desired subject in detail.

63. Field records and computations.—Field records and computations include all field notes normally recorded in special field notebooks or on special forms and all computations made by field parties or at field headquarters. Computations that pertain to surveying and topographical work are to a great extent calculations based on observations in the field and constitute the final phase of obtaining the necessary controlling data on which topographical and other maps are based. While most computations are made on special forms, some minor computations, of which only the final values are recorded, are often made to complete certain field notes.

64. Checking methods.—It is sometimes necessary to check certain data obtained from field notes and field computations before using same in the drafting room. This checking is usually made by methods independent of the first computation and may involve the

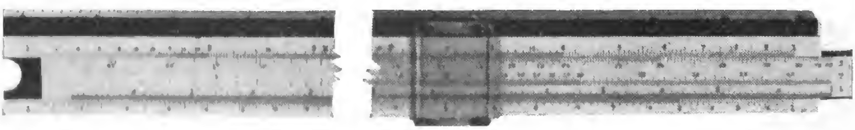


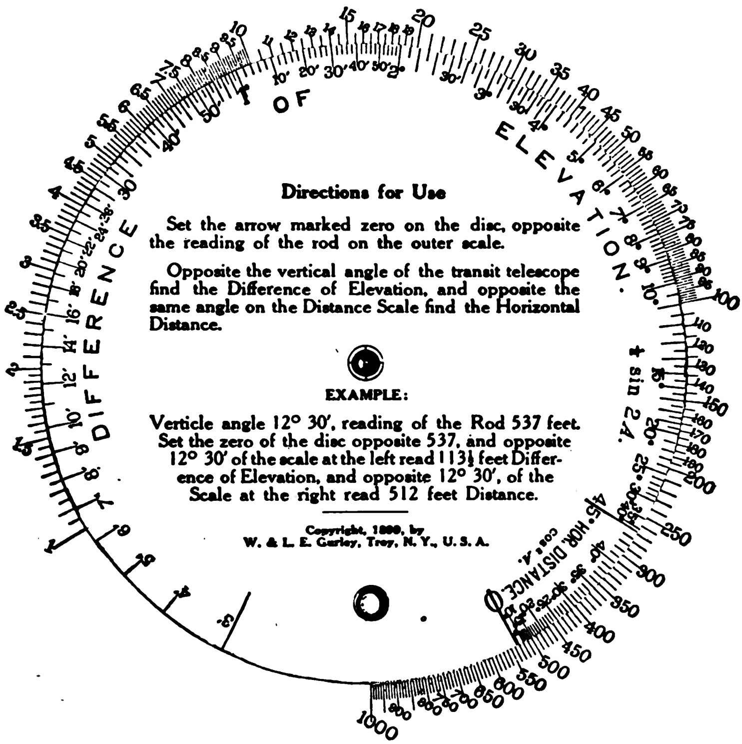
FIGURE 131.—Mannheim slide rule set to check departure for 118 yards distance with bearing of 12°40′.

use of calculating machines, Mannheim slide rule (fig. 131), stadia computer (fig. 132), special slide rules, and special diagrams and charts (fig. 133). For detailed description and use of these see TM 5–235.

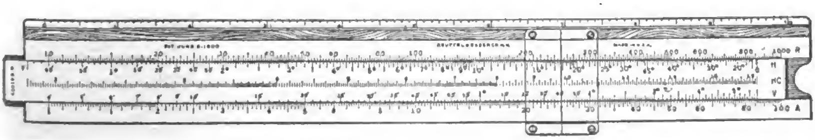
65. Independent office computations and adjustments.—Independent office computations and adjustments include certain check computations referred to in the preceding paragraph and computations incidental to office work, such as are necessary for laying out projections, grids, plotting of incomplete control data, etc. These computations are made in accordance with instructions described in detail in the various sections of TM 5–235, and can be easily found by referring to the alphabetical index of same.

66. Conversion of geographic data to grid data.—The draftsman will frequently be called upon to convert geographic data, such as geographic coordinates, azimuths, etc., pertaining to ground control stations, into grid coordinates and grid azimuths. Geographic data are usually furnished by other survey and mapping agencies

and must be converted to conform with the military grid system of the United States. Figure 134 shows the comparative relation be-



① Cox's stadia computer.



② K. and E. stadia slide rule.

FIGURE 132.—Stadia computer and stadia slide rule settings for obtaining differences of elevations and corrections for horizontal distances.

tween geographic and grid data. For a detailed discussion and directions for converting geographic data to grid data see paragraph 117, TM 5-235.

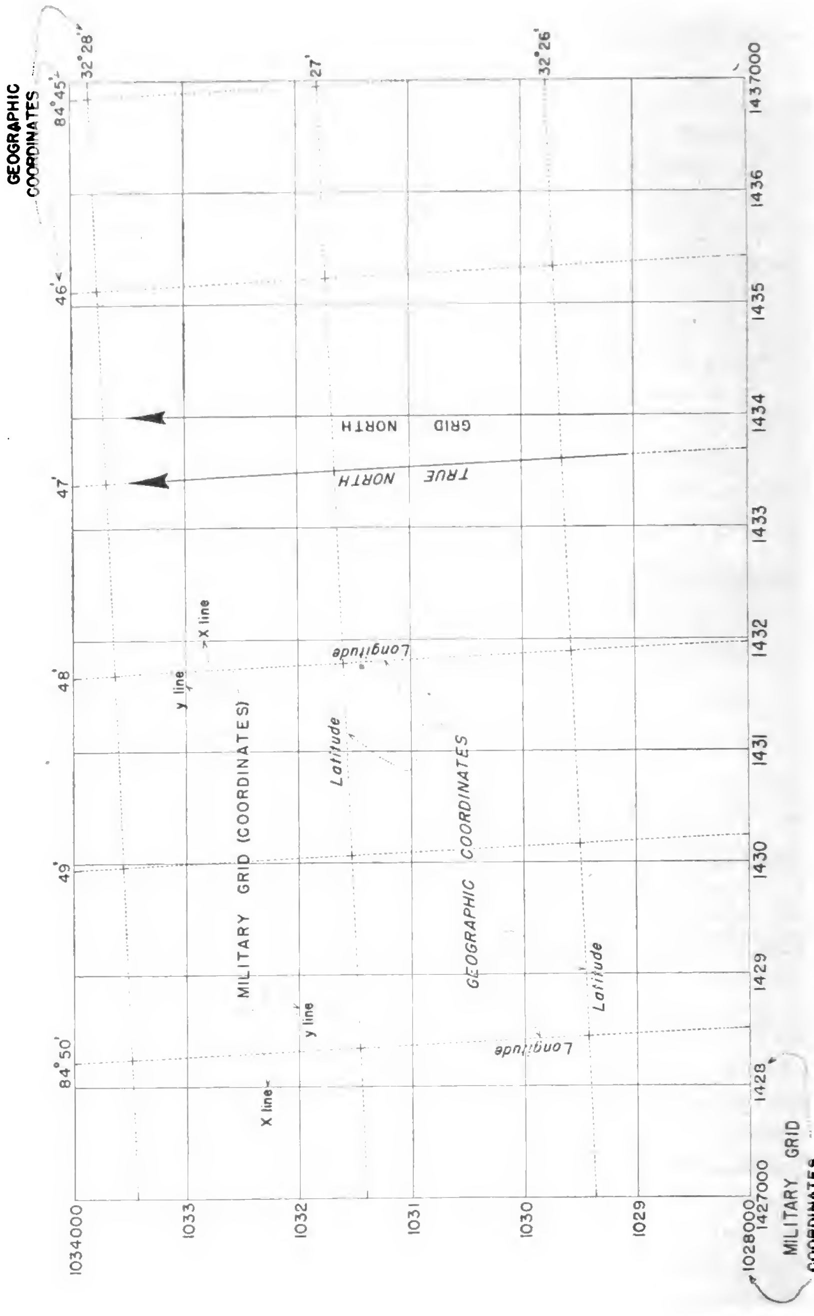


FIGURE 131.—Plot showing comparative relations between geographic data and grid data.

Section XIII

PLOTTING METHODS

67. Traverse plotting.—*a. General.*—(1) The plotting methods in this section are used for maps of smaller areas where the earth's surface can be considered plane. They are applicable to all types of surveys and are used mostly at the beginning of making a map. In general, these methods concern themselves with the plotting of horizontal control. Such control may be plotted by use of the protractor and scale, by the tangent method, chord method, or rectangular coordinate method.

(2) The two methods in general use are the protractor and scale method, also expressed as "plotting by polar coordinates," and the rectangular coordinate method, both described below. Control stations are indicated by appropriate symbols (FM 21-30, p. 7) lines being drawn with a fine-pointed hard pencil, 6H to 9H.

b. Plotting by polar coordinates.—(1) Ordinarily this method is used only when the control system, usually a traverse, is not extensive, or when the position of certain stations must be plotted before their rectangular coordinates have been computed. Since a protractor is used to plot the angular values, either from direct angular measurements or from azimuths and bearings, and since the precision with which angles can be laid off varies directly with the diameter of the protractor, it is of advantage to use the largest protractor available.

(2) In plotting the stations of a traverse by the actual angular values between them, the position of the first point is fixed by estimation, if not previously known, and a fine line of indefinite length is drawn in the direction of the second point. Along this line is laid off the given distance between the first and second point. The protractor then is placed with its center at the second point and its 0° to center edge along the line just drawn, and the angle to the succeeding point marked. A fine line is then drawn connecting the angle mark with the second station, and the given distance from the second to the third station laid off along this line, which establishes the position of the succeeding point. The process is repeated for each traverse point until the entire traverse is plotted. When stations are to be plotted from azimuths or bearings, it is best to determine and draw the meridian—true or grid north—and plot all angles in logical succession by their bearings with respect to the meridian. If azimuths only are given they must be converted to

their corresponding bearing for plotting. For a discussion of azimuths and bearings, etc., see paragraph 76, TM 5-235. The weakness of plotting stations successively from previous stations is that an error, once made, is carried in locating succeeding stations.

c. Exercise No. 23: plotting traverse by polar coordinates.—(1) Plot the traverse from the given azimuths and distances given in figure 135, according to the method outlined in *b* above, using a 1:20,000 scale.

(2) Finish the sheet as indicated in the figure, showing all lines and numerals, etc., in black ink and all station symbols in red ink.

d. Plotting by rectangular grid coordinates.—This plotting method is the only practical and satisfactory one for plotting the positions of control stations in any system of horizontal control. The rectangular coordinates (or grid) having been constructed, and the lines numbered (par. 60) so that all the points to be shown will fall within the numbered area, each station is plotted as follows:

(1) After comparing the rectangular coordinates of the station (found in the "coordinates" column under "northings" and "eastings," respectively, on the traverse sheet) with the numbered lines, select the proper square within which the station to be plotted will fall.

(2) With a pair of dividers lay off along both south-north lines bordering this square the difference in northings between the stations and the grid line below it.

(3) Draw a fine line connecting the two prick marks made with the dividers, using a single triangle. This line should be perfectly parallel to the west-east lines.

(4) Now lay off along this newly drawn line the difference in eastings between the station and the 1,000-yard grid line to the left of it.

(5) Mark and label the plotted station.

(6) Repeat the operations in (1) to (5) above until all stations are plotted.

(7) For a check always compare the scaled distance between the two last plotted stations with the known recorded or computed distance.

e. Exercise No. 24: plotting traverse by rectangular coordinates.—(1) Plot the traverse from the given data in figure 136 according to the method outlined in *d* above, using a 1:20,000 scale. The given data represent a traverse sheet showing the computations of the final adjusted values of coordinates (northings and eastings) for every station of that traverse, with distances in yards.

(2) Before attempting the plot by this method a study of TM 5-235 is necessary, so that the draftsman is familiar with the data shown on the traverse sheet.

(3) The reduced diagram in figure 136 illustrates how the finished sheet should appear. The work is inked, all lines and numerals, etc., black, and all station symbols red.

68. Control plots.—*a. General.*—(1) Control plots include all drawings on which horizontal control stations are plotted for the purpose of serving as a base in making topographic or other maps. As a rule, as soon as the control data obtained in the field by the survey parties are available, a control sheet or several of them, if necessary to cover the area to be mapped, are laid out. A good drawing paper mounted on metal or muslin or topographic (nonshrinkable) film base should be used. As predetermined grid lines usually are the borders of each map sheet, control sheets are prepared to conform thereto. The control sheets also show all intermediate grid lines.

(2) Computed control data must be made available to field parties as early as possible, and the field parties themselves, or a computing section in direct contact with the field parties, should compute all data required from the observations. If necessary a transcript of all data must be prepared for the drafting room, or two sets of books be kept alternating between the field and the computing office.

(3) A complete control sheet shows all ground control points established by traverses or triangulation and in addition all adjusted photographic control points as determined by the radial line method (par. 78) or by one of the templet methods (par. 79).

(4) Control sheets are normally inked in black, with control points and their numbers in nonphotographic blue.

b. Ground control.—The ground control on control plots is usually plotted by rectangular coordinates from the computed coordinates for each station or control point. All points are labeled with their correct designation. It is sometimes an advantage to list elevations and azimuths pertaining to ground control points along the borders of the control sheet. Ground control may be termed the primary control for the area mapped (not primary, however, as applied to geodetic surveying).

c. Photographic control.—This control, described in detail in paragraphs 78 and 79, includes the graphically adjusted positions of points common to two or more aerial photographs as selected on them. These points are brought into horizontal agreement with all related ground control points identifiable and marked on the photographs used. The photographic control is first plotted and adjusted separately and the adjusted positions only of each point transferred onto the control sheet. To do this, if the slotted templet method (par. 79) is used, the

ground control is plotted as usual; then templet studs are set through all ground control points shown on both the control sheet and templets and all templets laid and studded over the control sheet. After proper alinement the mechanically adjusted position of each photographic control point is pricked through the hollow studs into its proper place on the control sheet, bringing the photographic control points into perfect horizontal agreement with the ground control points. All of the photographs' center points are labeled with their proper number for easy and rapid identification.

d. Exercise No. 25: construction of ground control sheet.—(1) Construct a control plot, to be used later in exercises Nos. 28 and 29, to a given average scale of photographs for a map area extending 8,000 yards from south to north and 10,000 yards from west to east, and show: the 1,000-yard grid (par. 61), one 5-minute meridian, one 5-minute parallel of latitude, and all available known ground control, the grid coordinates of the ground control points within the area and the designation of the grid zone being given. The method of constructing this type of control plot is explained best by using specific figures covering a typical problem. Assume that the following data are given:

Station	*x coordinates*	*y coordinates*
Bluff	930439. 0	1337615. 7
Hill	928853. 5	1344218. 3
Knob	937394. 2	1343847. 1
Top	935521. 8	1338302. 5

Location of area in grid zone C; assumed average scale of photographs to be used later on 1:19,500.

(2) Obtain an accurate plotting scale in yards conforming to the given average scale of photographs—1:19,500. If none is available, construct one by the method explained in paragraph 23*b* (fig. 85).

(3) On a sheet of suitable drawing paper or film base construct a 1,000-yard rectangular grid system, 8 squares high and 10 squares wide, making sure that the net of squares is perfectly true by checking the two diagonals and the diagonals of different series of squares. Number the grid lines to conform to the given grid coordinates of the ground control points (fig. 137).

(4) Plot (and label) the ground control points, using the given coordinates, by the method explained in paragraph 67*d*.

(5) Ink the work, completed so far, with black ink, except ground control point symbols which may be in red or blue.

(6) It remains now to lay off one 5-minute meridian and one 5-minute parallel of latitude. In most cases only one intersection of a

5-minute interval of latitude and longitude will fall inside an area of 8,000 by 10,000 yards. Sometimes this 5-minute interval of longitude will fall just outside the border of such area.

(7) Using Special Publication No. 59, U. S. Coast and Geodetic Survey, follow "Method of placing the spherical projection on special military maps" (pp. 15 and 16). Comparing the plotted grid coordinates with those in figure 129, it is found that the general location of the area is in the vicinity of 35° latitude and about 1° west of the central meridian (of zone C near the 90° longitude). Inspecting the tables in Special Publication No. 59 with this general information, we find (p. 107) that the intersection of the 5-minute interval of latitude 35°05′ and longitude 89°40′ falls within the area plotted, the grid coordinates of this intersection being found (on line 9) as x=933540.9 and y=1342748.8. Plot the intersection from these coordinates.

(8) To plot the lines representing the latitude (35°05′) and longitude (89°40′) proceed as follows:

(*a*) As the longitude to be plotted lies west of the central meridian (89°) of zone C, and all vertical grid lines are parallel to the central meridian, the longitude (89°40′) leans or converges a certain amount toward the north in the direction of the central meridian, or a like amount in the direction of the nearest vertical grid line shown on the plot east of the longitude to be plotted.

(*b*) This convergence, given for intervals of 1° in longitude and latitude, is taken from the table on page 33, Special Publication No. 59, U. S. C. and G. S., and must be interpolated for the 5-minute intersection to be plotted on the sheet. This angle of convergence is best calculated as follows: Basic figures from the table, copied here, are italicized. The value for 35°05′ and 89°40′ is the interpolated correction, amounting in this case to *0°22′59″*.

Latitude	*89°*	*89°40′*	*90°*
35°	*0°00′00″*		*0°34′25″*
35°05′	0°00′00″	[2] *0°22′59″*	[1] 0°34′29″
36°	*0°00′00″*		*0°35′16″*

(*c*) Since all values in the 89° (central meridian) column are 0°0′00″, the interpolation for the 35°05′ latitude is 0°0′00″.

[1] 0°34′29″ is the result of the first interpolation obtained by adding one-twelfth (5 minutes is one-twelfth of a degree) of the difference between the two values in the 90° column to the lesser angle.

[2] 0°22′59″ is the result of the second or final interpolation by adding forty-sixtieths (40 minutes is forty-sixtieths of a degree) of the difference between 0°00′00″ and 0°34′29″ to 0°00′00″.

(*d*) The line representing the 89°40′ longitude can now be drawn through the previously plotted intersection of 89°40′ longitude and 35°05′ latitude shown in figure 137, extending from north border to south border and converging 0°22′59″ east in its northern direction from the intersection. Erect a perpendicular line to the just completed longitude line from the 35°05′ intersection extending same from the west to the east border. This line represents the 35°05′ parallel of latitude. Ink the intersection of the two lines and their end ticks and complete the sheet as shown in figure 137.

(9) Figure 138 shows a complete control sheet containing both ground control and photograph control, the latter obtained and plotted by the use of the slotted templet method.

69. Flight, index, and progress plots.—*a. Flight diagrams.*—Flight diagrams serve as a guide for the plane pilot to fly over predetermined courses so that suitable aerial photographs may be obtained. The area to be photographed is plotted on any map suitable for flying. While the pilot can follow the courses more accurately on a 1:62,500 topographic map in colors, a large area map of that scale would be inconvenient to handle. Large areas have been successfully photographed while flown from 1:500,000 maps showing only important planimetric detail. If no suitable map can be obtained, it may be necessary to have a preliminary study of the area made from the air, during which a rough sketch should be made showing the location of landmarks needed to guide the lines of flight. During such a mission, photographic strips may also be made of the boundaries at which the proposed strips will be begun and ended. These photographs may be mounted in the form of rough strip mosaics surrounding the area and so serve as a basis for the flight diagram. In either case, the proposed lines of flight are next plotted, preferably paralleling the longest way of the area to be mapped (fig. 139). These lines serve as guides for the pilot when flying back and forth across the area during photographic operations. The lines of flight are so spaced that the strips of photographs, as each line is followed in flight, will overlap the adjoining strips in the amount desired. If the photographs requested are 9 by 9 inches at a scale of 1:20,000, the width covered by a single negative is $\frac{9 \times 20{,}000}{12 \times 5{,}280} = 2.84$ miles. For 30 percent sidelap, the distance between flight lines on the flight diagram would be $.70 \times 2.84 = 1.99$ miles. If the project is to extend from a controlled area into enemy territory beyond known control, the flight lines should be about perpendicular to the general course of the front line of control points.

b. Exercise No. 26: preparation of flight diagram.—On an assigned map of medium scale, prepare a complete flight diagram similar to figure 139 to accompany a request for photography (par. 44*c*). A list of control points, and a description of the boundary of enemy territory to be covered (by geographic or grid coordinates or by physical features or place names) should be furnished.

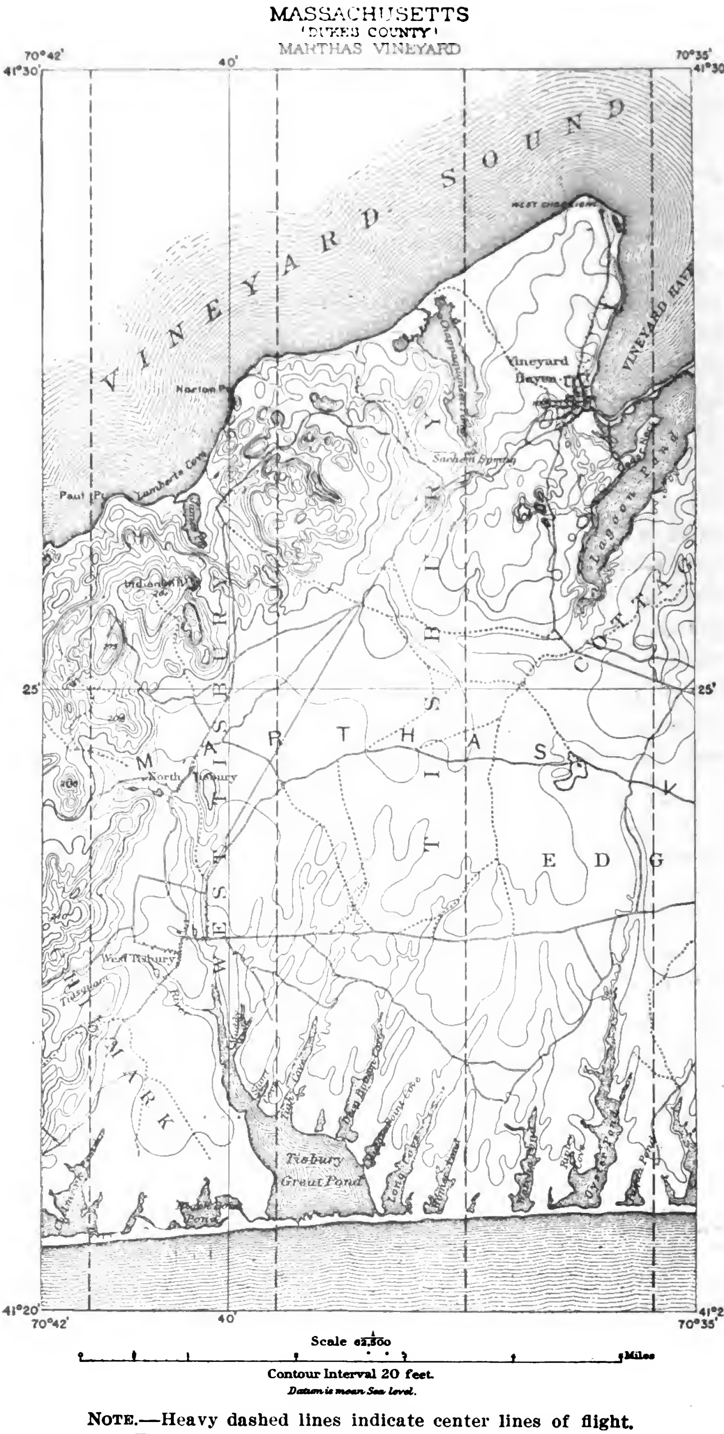
c. Index maps.—(1) After numbering the negatives, the Air Corps checks to make certain that the area is fully covered by photographs with the specified forward and side overlaps. The photo section usually makes an index map, which will be forwarded with the prints and any other data requested. If time presses or the index map is needed elsewhere, only a data sheet is sent with the prints. In that case the receiving organization may make an index map which will facilitate the use of the prints in several ways. The exact procedure depends upon the time and material at hand.

(2) A duplicate of the flight map usually serves as a base for an index map (fig. 140). By comparison of map detail at the corners of one or two prints, a rectangular celluloid templet of suitable size is cut, which is used to outline the two photographs at each end of each flight. These rectangles as outlined are numbered and, if desired, the outline and numbers of the other photographs may be marked, properly spaced, along the flight lines.

(3) If no map is available, an index diagram may be made by laying out the middle flight, and using a celluloid template of suitable size plotting the two end photographs and about every fifth or tenth photograph in the middle of each flight, marking each with its number. Proceed by laying out the next two flights and trace and number the outlines of photographs adjacent to those already marked from the middle flight.

(4) If there is no suitable map, an index mosaic may be made rather quickly by laying out all the photographs in the form of a rough mosaic and photographing to a reduced scale (fig. 141). Illegible numbers will have to be remarked on the print of the mosaic.

d. Progress charts.—Coordination and systematic procedure are essential in any work having so many stages as map making. Especially when time is limited, a record in the form of progress charts must be kept of the progress of each step to insure maximum output at all times. For such charts an index diagram, an obsolete map, or even a series of photomaps mounted together may be used. For each stage the completed areas may be outlined with colored pencil according to an appended legend. Without some such guide, unnecessary delays and disappointments are inevitable.



Note.—Heavy dashed lines indicate center lines of flight.

Figure 139.—Flight diagram (exercise No. 26).

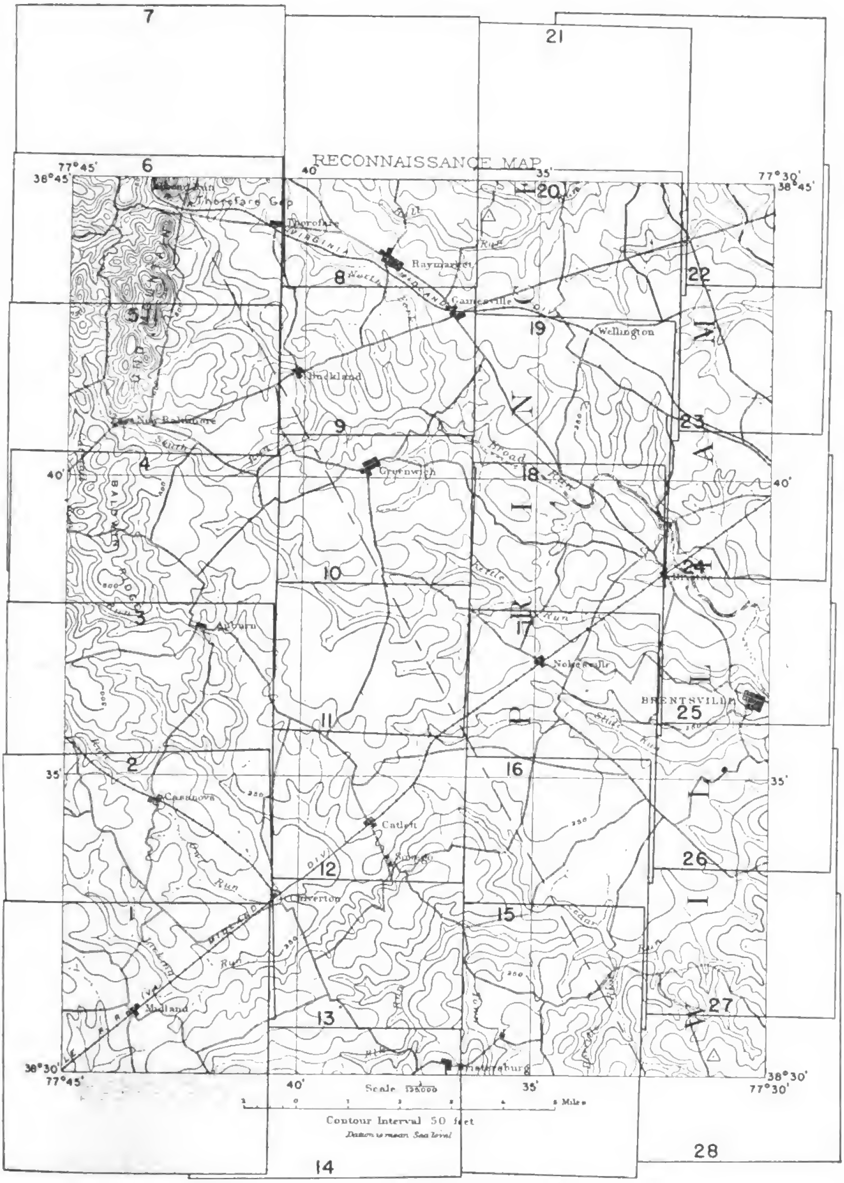


FIGURE 140.—Index map showing coverage of areas by 9- by 9-inch K-3B photographs.

SECTION XIV

CHARACTERISTICS OF AERIAL PHOTOGRAPHS

70. General.—The aerial photograph is a perspective projection (par. 56) formed on the plane of the film which cuts the conical bundle of rays within the field of view of the camera lens. For surveying purposes the aerial photograph may be considered as a complete record of all rays of light from objects on a limited portion of the earth's surface through the lens of the camera. The rays are registered on the sensitized surface of the film held in a plane perpendicular to the optical axis of the lens. The intersection of the axis of the lens with this perpendicular plane determines the principal point of a photograph. The position of the principal point may be found near the center of each negative or print at the intersection of lines drawn through pairs of collimating marks registered on the margins. In mapping cameras the correct distance between lens and film is maintained by rigid construction. During exposure the film is held flat in the focal plane by a glass pressure plate or other means. The equivalent focal length and the principal point are determined by camera calibration. The focal length is furnished on the data sheet accompanying the photographs, and the position of the principal point is obtained from the collimating marks near the edges of the photographs.

71. Effect of relief.—*a. General.*—An aerial photograph of perfectly level ground taken by a camera with its axis truly vertical would give the true map positions of all points directly. As the terrain is never perfectly level, the effect of perspective will be present in all verticals. The displacements due to differences of elevation radiate from the plumb point, which is the point vertically beneath the lens at exposure. In a truly vertical photograph the plumb point image coincides with the principal point. The tops of the silos and buildings in figure 142 all radiate from the plumb point. The hilltop also is displaced, though the displacement is not so apparent from the photograph.

b. Amount of displacement.—In figure 143, h_a and h_b represent the elevation differences of A and B below and above the datum plane, which is assumed at the ground elevation of the plumb point. The effect of ground relief on the photographic images is exaggerated because f, h_a, h_b and H are not in true proportion. If the ground

FIGURE 142.—Vertical from low altitude.

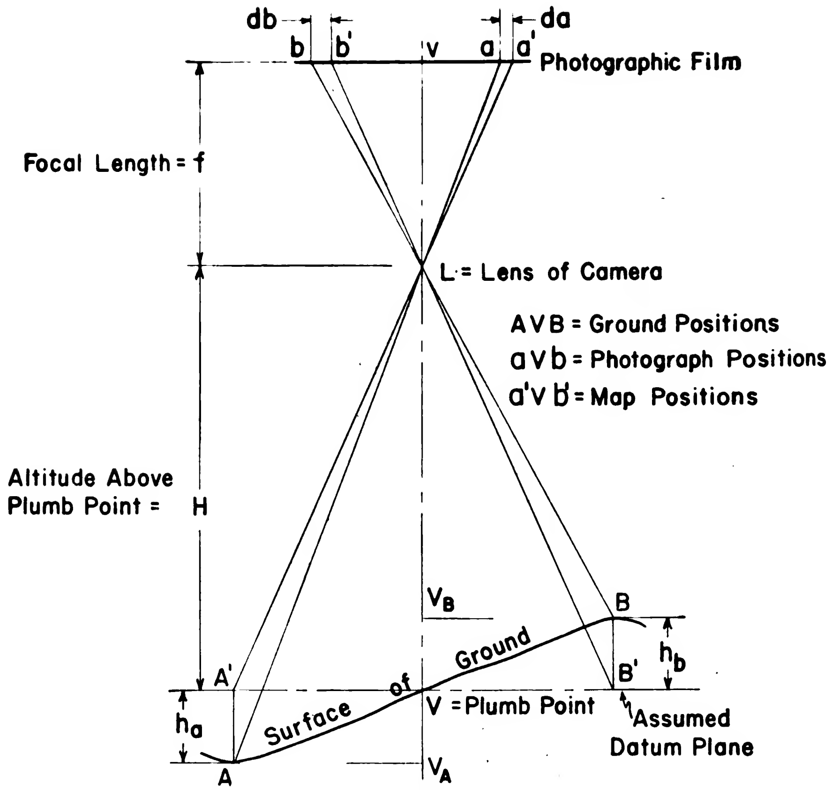


FIGURE 143.—Displacement of photographic positions due to ground relief.

were level, all distances on the photograph would have been to the scale $\frac{f}{H}$, assumed here as the map scale. On the photograph, the scale of the distance va is $\frac{f}{H+h_a}$, and of vb is $\frac{f}{H-h_b}$. Thus the perspective displacements, d_a and d_b, between the photograph and map projections of the image points are inward toward the plumb point image if the terrain is lower, and outward from the plumb point image if the terrain is higher, than the ground at the plumb point. By similar triangles

$$d_a = \frac{(va)\,h_a}{H} \text{ and } d_b = \frac{(bv)\,h_b}{H}$$

Therefore, the displacement increases with the difference of elevation from that of the plumb point; and the distance of the image from the plumb point on the photograph; and decreases as the altitude is increased. These three factors in relative relief displacement are

demonstrated graphically in figure 144. Careful inspection of the figure will reveal no displacement at elevation 500, which was assumed as the datum plane in this case.

c. References.—Section VII explains how these perspective relief displacements make stereoscopic vision possible, and how the sketching of form lines and the interpolation of contours from spot elevations are accomplished. Section XVIII will show how the amount of displacement can be measured and utilized in determining elevations and tracing contours from the stereoscopic model. Moderate differences of elevation may cause plottable errors in tracing topography from verticals. The radial line and templet methods of section XVI are designed to correct such errors by restoring the displaced features to their true positions. The difference in scale due to heavy relief is the most difficult of adjustment. Because the net altitude of the camera above the terrain is less for high ground than for low, the features and detail of the summits will be photographed at a larger scale than those of lower elevation.

72. Effect of tilt.—*a. General.*—In making verticals the optical axis of the camera is almost never vertical. The action of air currents, the banking and tipping of the airplane in the effort to keep a straight, level course, and perhaps an occasional break in the coordination of the pilot and photographer all tend to keep the camera from the desired position. In the more tranquil air of higher altitudes, and with the best possible equipment, well-trained personnel of experience may combine to keep tilt mostly within 1° of the vertical and to prevent any tilt exceeding 3° at the moment of exposure. Tilt perpendicular to the direction of flight may be designated as lateral tilt, or simply tilt; in the direction of flight as tip. Any deviation from the vertical introduces perspective distortions into the photograph, which makes it impossible to determine ground distances by direct measurements on the photograph.

b. Results of tilt.—Figure 145 shows a section in the plane of the plumb line and the optical axis of a camera tilted 15° from the vertical. A square, *AB*, on level ground is being photographed. It is assumed that a positive, called the equivalent positive, has been made from the negative and placed perpendicular to the optical axis at the focal distance below the lens, so that rays from the ground points would have each passed through the corresponding points *a*, *v*, *i*, *p*, *b*. The square diagram of the positive shows that the perspective changes due to tilt are radial from the isocenter *i*, the point about midway between the principal point *p* and the plumb point *v*. It is evident that the distortion increases from zero at the isocenter toward the

edges, except on the axis of tilt. The latter represents the intersection of a truly vertical and a tilted photograph taken from the same air station, and so is the only line of true scale on the tilted photograph. The axis of tilt is normal to the direction of tilt and passes through the isocenter. In the direction of tilt from the axis of tilt, all lines are longer than on a truly vertical photograph. On the side of the axis opposite the direction of tilt, all lines are shorter than on a photograph of true scale. Tilt distortion is greatest for points farthest from the center of the photograph in the direction of tilt.

c. Combined effects of relief and tilt.—Taken separately, the effects of tilt and relief follow simple rules. Together, these effects may be cumulative or compensating. The displacements due to tilt are radial from the isocenter while those due to relief are radial from the plumb point. The positions of these two points could be determined if the degree and axis of tilt were known. Such determination is a lengthy process, if accuracy is required. Attempts have been made to indicate the tilt by level bubbles and other means, without reliable result. Fortunately, the distances of the isocenter and plumb point from the principal point are reduced as the tilt decreases. Straight level flying and careful photography keep the differences so small that they may be disregarded. If the tilt never exceeds 3° and the elevation differences are no more than 10 percent of the photographic altitude, the principal point may be assumed as the center from which displacements of combined tilt and relief are radial. This assumption is the basis of the radial line and templet methods of section XVI.

d. Cause and effect of crab.—In supplementary control work, in interpolating elevations, in contouring, and, in fact, in any method of using photographs quantitatively, the best results are invariably obtained from straight, parallel strips flown at a constant altitude. This kind of flying is so advantageous for all mapping procedures that its importance cannot be overemphasized. The unavoidable distortions due to relief and those caused by minimum tilts are troublesome enough. Crooked flight lines indicate additional lateral tilt, and variable altitudes cause changes of scale, usually associated with tip in the process of getting back to the proper altitude. Crab is undesirable as it affects the symmetry of the supplementary control and detail plotting without any resulting advantages. Crab is caused by failure to rotate the camera about its vertical axis so as to compensate for the drift of the plane caused by a cross wind. In that

event, the sides of the photographs are not parallel to the line of flight, as they should be for best results with strips of single verticals.

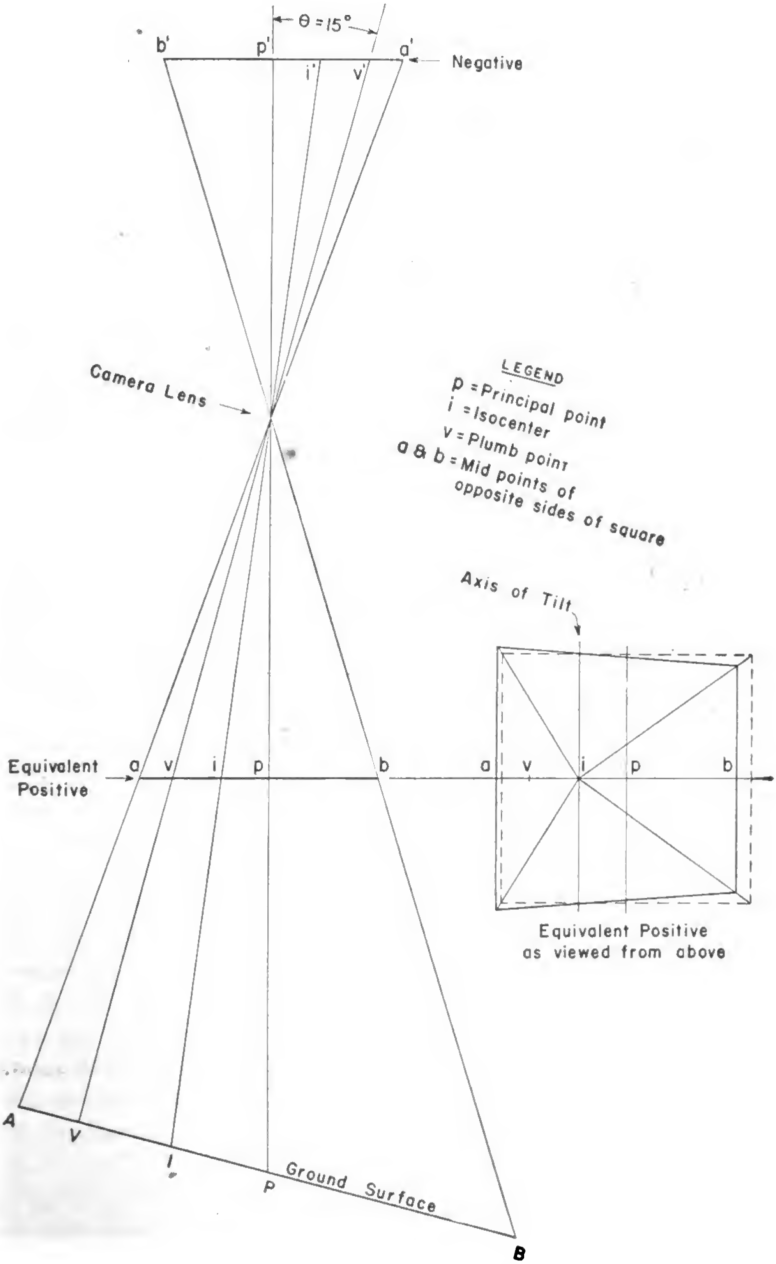


Figure 145.—Displacement of photographic positions due to tilt.

Section XV

PREPARING PHOTOGRAPHS FOR MAPPING

73. Care of photographs.—*a. General.*—Immediately after receipt, the photographs should be inspected for clarity of detail and general condition. Referring to the original request, the number of prints from each negative and the total should be checked, and the receipt of the required data verified. Commencing with the middle flight, followed by the others in turn, a set of prints should be laid out by approximately matching detail to check the availability of the required overlap and the general coverage of the area. The index map should be made at this time, if none has been received. All pertinent items should be copied from the data sheet to the margin of the index map, which will be kept on file.

b. Indexing.—While the index map shows what photographs have been received and presumably filed, a separate record should be kept for the prints in current use. As prints are removed from the file, the numbers, date, person to whom issued, and the project are entered in a register kept for the purpose. As the prints are returned to the file, the numbers are canceled and the completion date of return is marked opposite the original entry. During a mapping project, especially if the work is divided among many men, the prints are not returned to the file. The man in charge or an assistant keeps a current record of the use being made of the various strips as he maintains the progress chart showing the stage of completion of the several steps.

c. Filing.—In addition to the complete file of index maps, provision will have to be made for storing such prints as may prove useful in the future. The cardboard boxes in which the manufacturer packs the photographic paper are quite suitable for this. If the boxes are well filled and securely tied, the prints will be kept in good condition and uncurled by changes of weather. By marking the contents of each box on the end, the desired strip or set can be picked out at a glance. If prints are not boxed they should always be kept flat in neat tiers under weights.

74. Mounting photographs.—*a. Single verticals.*—These are usually printed on double-weight paper. In such material, paper distortion is considerably diminished. With reasonable care in keep-

ing double weight prints pressed flat when not in use, mounts to prevent curling are unnecessary. They should be left untrimmed to prevent damage to the edges when the stereo-comparagraph is employed. For any use whatever, single weight paper prints must be mounted with rubber cement on stiff, thin cardboard.

b. Composites.—(1) *General.*—Before mounting the component prints of vertical composites for mapping by the methods of section XVI (if the special stereoscope of paragraph 75*e* (3) is not available), all the principal points, substitute centers if used, ground control points, wing points, tie points, and auxiliary control points should be marked as described in paragraph 75. These points must be marked not only on the photographs where they originate but also on other photographs covering the same terrain. The transferring of points from the photograph of origination to adjacent prints can be most accurately accomplished under the stereoscope. The difficulty of obtaining stereoscopic vision after the prints are mounted on the 33-inch boards necessitates the completion of the point marking before mounting is commenced.

(2) *To trim prints.*—(*a*) Obtain a special Air Corps print trimmer fitted with millimeter scales and window plates, and a trimming and alinement data sheet for the particular camera used.

(*b*) Normally, the print trimmer must be set differently for each A, C, D, and E series of oblique prints and for the B prints. This setting must be made accurately and by means of setting each hair line at the proper figure on its scale in the surface of the trimmer base. These figures have been determined during the calibration of each camera and are given on the trimming and alinement data sheet (fig. 146). Each hair line should be set to within 0.2 mm.

(*c*) In trimming, the print is placed on the base of the trimmer with the knife raised. The window plates are pressed down lightly upon the print with the thumb and fingers of the left hand, and at the same time the print is moved by the right hand so that the hair lines fall upon the collimating notches at the edges of the print. The left hand then presses down upon the window plates with sufficient force to prevent movement of the print, and the right hand operates the knife to trim the print. Four cuts are necessary for the B print and one cut on each of the oblique prints.

(3) *To mount photographs.*—(*a*) Each set of T-3A instruments (camera, printer, and accessories) includes an alinement templet bearing the number of the set. This templet consists of an aluminum sheet with openings having straight faces along which lines may be drawn. Three such openings are provided for the B print and one

each for the A, C, D, and E prints. The relation between the prepared faces of the slots of the templet is determined separately for each camera at the time of calibration.

(*b*) Because of this predetermined alinement, always join and mount the trimmed prints in the following manner:

Use a sheet of photographic mounting board material 34 inches square. Center the alinement templet on the mounting sheet, and

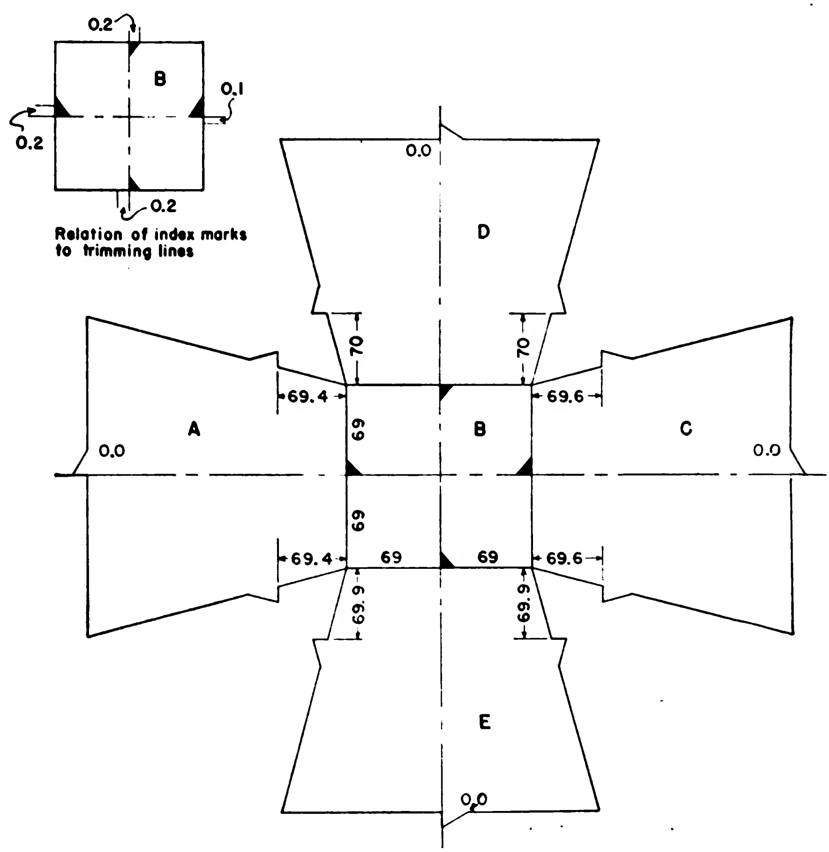


FIGURE 146.—Trimming and alinement data sheet for T–3A camera.

using the straight faces of the templet slots as straight edges inscribe fine lines on the mounting sheet. Use a hard pencil, well-sharpened, or a fine metal stylus.

(*c*) Unless the composite print is symmetrical, that is, unless the offsets of all oblique prints from the center lines of the B print are the same (as shown on the trimming and alinement data sheet), proper notations must be made on the mounting sheet when the

templet is removed, in order to insure proper arrangement of the prints. The B print must be mounted first upon the three lines made by using the B openings of the alinement templet, so that the four notches of the photograph fall exactly on the lines. If the composite print is unsymmetrical, determine which way the center print is to be mounted by laying down any oblique in its place and turning the B print until it matches. The wing prints are mounted, each with the outer collimating notch exactly on the line drawn for it with the alinement templet in (*b*) above, and with the detail of the inner edge matching the corresponding edge of the B print. To prevent buckling, 0.25-mm. separation between the edges is allowed for on the data sheet. Held at this distance the detail of the trimmed edges should be continuous within plus or minus 0.4 mm. If not, and the error cannot be found in the setting of the print trimmer, the calibration data may have to be rejected and redetermined. The composite photograph, properly trimmed and mounted, may be considered a single vertical.

(*d*) The best type of mounting both for speed and accuracy is done by stapling the prints to the mounting sheet with a wire-stapling device. In this method, the staples should be about 3/8 inch long and the stapling device should clinch the staple ends on the back of the mounting sheet securely. The advantages of this method of mounting are increased accuracy, elimination of shrinkage due to heat application when using dry tissue, speed, and ease of remounting badly mounted prints.

(4) *Hand trimming.*—Under exceptional circumstances composites may be trimmed by hand to the dimensions given on the trimming diagram for the camera used (fig. 146). Every part of this work will require extreme care.

c. Stereo-pair.—(See par. 27*e*.) Occasionally the prints of a stereo-pair are trimmed to include only the portions actually overlapping and are mounted in the form of a stereogram, which may be used for instruction in the use of the lorgnette stereoscope. Place and secure the prints by the precise method of paragraph 35*m*. With a mirror stereoscope, make certain that all parts of the overlap are in correspondence. On each of the prints outline the common areas to be retained for the stereogram by ruling lines parallel to and at right angles with the line between centers. With a sharp knife or razor blade, trim away the parts to be discarded. Mount the components of the stereogram side by side on a piece of cardboard.

d. Stereo-triplet.—(See par. 27*f* and fig. 95.) These are prepared by the method described in *c* above, except that two separate lines

of centers are used. The three prints are secured in correspondence. The top and bottom edges are trimmed by parallel lines drawn straight across all three prints. The joining edges of the three prints and the outer edges of the retained portions of the right and left prints are trimmed on lines drawn perpendicular to the top and bottom edges.

75. Selecting and marking control points on photographs.—*a. General.*—In the photographic control and adjustment methods of section XVI, the transferring of identical points from one photograph to those adjacent is necessary. Some of these points may be distinctly marked points of detail selected for the purpose, but others, such as the principal point, may not be so situated. In any case, a stereoscope should be used for this purpose, as the appreciation of relief is very helpful. The diopter glasses or lorgnette, mounted on the adjustable stand for the 2-inch reading glass, are quite suitable.

(1) A very convenient device to aid in the transfer of identical points has recently been constructed. It consists of two small bronze frames which carry flat glasses etched on the lower side with symmetrical black crosses having arms extending about 3/8 inch from the center of the cross. The photographs are fused under the stereoscope, and the simple frame of the pair is placed with the center of the cross directly over the point to be transferred. The second frame is placed in a corresponding position on the other print; and moved into such relation with the photograph that the center of the single cross, as viewed stereoscopically, appears to be exactly at the surface of the ground at the point to be transferred. By means of a small lever, the glass in the second frame is lifted from the paper, and a pricker is turned down to mark the photograph at the point which was at the center of the cross.

(2) The above principle has been in use for several years, employing crosses scratched on transparent film base as in figure 147. How-

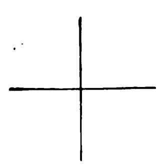


FIGURE 147.—Point marker.

ever, they are best made by cutting a fine cross of proper size on the film of a black photographic plate and printing and developing a supply on ordinary film. The two photographs are brought into

stereoscopic fusion and held down with weights or tape. One cross is placed over the point to be transferred, guiding it into place with a No. 10 needle passed through a small hole carefully pricked at the center of the cross. The lines of the cross should make angles of about 45° with the base line between the centers. The other cross is placed similarly over the corresponding part of the other photograph. The steroscopic view will show a single cross apparently floating in space, and the center of the second cross will indicate the transferred point when the center of the fused cross appears to touch the ground. The simplest way to obtain this result is to place the second cross a little closer to the first cross than the corresponding points on the prints. Then, keeping the arms of the cross in perfect fusion, move the second one slowly away from the first until the correct appearance is obtained. The new point is then pricked through the center of the cross and suitably marked. This method requires delicate manipulation and should be practiced until repeated trials show no appreciable difference in results.

b. Ground control points.—These are used to make sure that the map made from the photographs will fit the geographic and grid lines. These control points are the result of earlier surveys or are run in by triangulation and traverse from control already established. The map positions of the ground control points are then computed and adjusted, and the points are accurately plotted on the map control sheet to form a framework on which to compile the topography taken from the photographs. For this purpose the control points must be marked on the photographs, wherever they occur. To avoid map errors, the positions of these points on the photographs must be carefully plotted and verified. An error in identification or plotting control points on the photographs is equivalent to an error of the same amount in determining the position of the point.

(1) In establishing ground control for photographic mapping, field parties must give due attention to the location of stations at picture points, siting them at road junctions, fence lines, railroad and stream crossings, or other points which may be positively identified on the photographs from descriptions or sketches. This is not difficult in traversing thickly settled country. In less developed areas, especially if heavily wooded, or in the case of triangulation stations, which have to be located for intervisibility with other stations of the system, points certain of identification may not be available.

(2) If such points are determined in advance of photography, it may be advisable to mark them with panels which will appear in the photographs. TM 5-235 contains instructions for plotting ground-

control points on the photographs in the field by relation to picture points which can be identified on the ground with certainty. Points which have to be plotted on the photograph in the field should invariably be transferred to adjacent photographs by the methods in *a* above.

c. Procedure.—(1) It was shown in paragraph 72*c* that with good flying over terrain of low or medium relief the principal point may be assumed as the center from which displacements are radial. In other words, the assumption is made that the true direction of an object from the center of the photograph is a straight line from the center of the photograph through the image of the object. From this principle it follows that if two photographs, overlapping more than 50 percent, can be properly oriented with respect to one another and their centers plotted, radial lines drawn from the centers through images common to the two photographs in their overlap will, at their intersection, establish the true position of such images at the scale of the line joining the centers of the photographs. This offers a system of graphic triangulation by means of overlapping photographs, which makes it possible to plot photographic control to any selected scale, using the course lines ((4) below) in the overlap to orient the photographs in each strip. The radial line and templet methods described in the next section are thus dependent upon the three-point principle of locating successive centers. The photographs to be plotted are arranged in numerical order in the several strips ready for marking.

(2) For easy visibility and permanence, all points, rays, numbers, and letters, if any, are marked on the prints with colored inks. The points themselves must be carefully pricked with a fine needle and may be dotted with a fine pen if desired for easy visibility. To increase accuracy and to avoid obscuring detail, lines should be as fine as possible. A line drawn from, through, or to a point must be stopped a short distance from the point itself, lest the exact position of the point be made uncertain. When dashes are used, they should be ruled normal to the ray and never be drawn through the point. They need not be over 0.2 inch over all. Circles may be 0.2 inch in diameter and triangles should be equilateral, with the point at the center and the sides about 0.3 inch long. For center, substitute center, ground control, and wing points, red ink is used, except in the darkest portions of the print, where bright yellow water color may be used. If the elevation difference or an overlap runs over 3 percent of the effective flight altitude, some auxiliary intersection points for correcting relief distortion will be needed as explained in section XVIII.

These auxiliary points and their radial lines should be marked with blue or green ink. Preparation for the radial line method (par. 78) includes marking the photograph with the following:

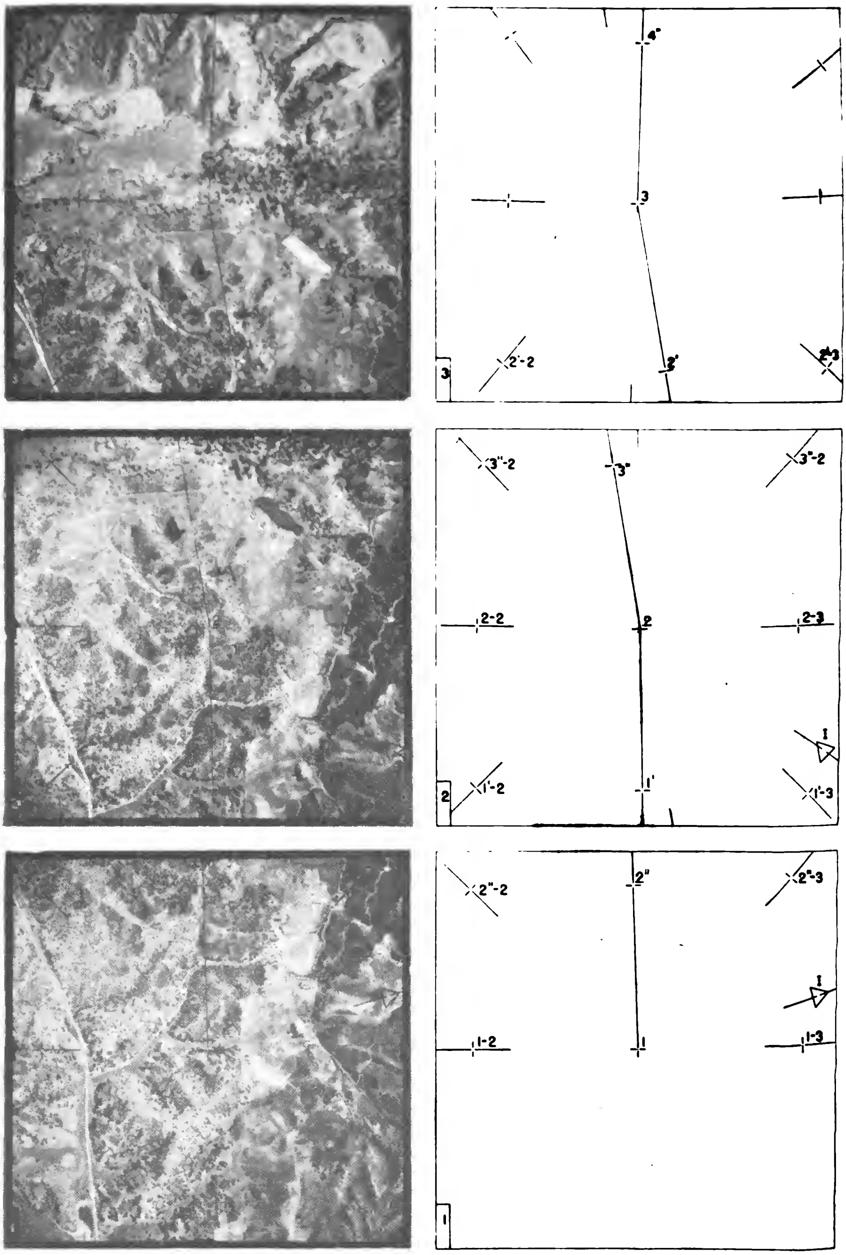
Principal points.
Substitute centers, if used.
Course lines.
Wing points with radial lines.
Auxiliary points with radial lines, if used.

For the templet methods (par. 79), all points are pricked and circled with a 0.2-inch diameter circle of the appropriate color, instead of being marked with dashes, but the course lines and radial lines are not required.

(3) The principal point, pricked on each print at the intersection of fine lines through pairs of opposite collimating marks, should be marked with an interrupted dash, not over 0.2 inch long, about normal to the flight line, 1, 2, 3, figure 148. Only the principal points need be numbered as in figure 148 ①. The additional numbers in figure 148 ② are only for the explanation of this method; all numbers in (4) to (9), inclusive, below refer to figure 148 ②.

(4) The course lines, which govern the orientation of the individual photographs and so determine the plotted azimuths of the strips, are drawn after all principal points have been transferred to the adjacent photographs by one of the methods of *a* above. The transferred points are marked by dashes normal to the flight line. The course lines are drawn from the principal point, through the transferred point, 1′, 2″, 2′, etc., straight to the edge of the print, and a "tick" is left at the opposite edge before the straightedge is moved. These ticks practically double the length of the course lines and so stiffen the azimuth plotting. If the principal point should fall upon the surface of a small body of water, it can still be transferred if the ends of the cross (see *a*(2) above) are long enough to reach the shores.

(5) Substitute centers may be used wherever there is any doubt as to the accuracy of transferring the principal point. The substitute center should be pricked and surrounded by a circle at a point of sharp, well-defined detail as near the principal point as possible, preferably not more than 0.2 inch away normal to the line of flight, and not over 0.4 inch away along the line. It is assumed that within these limits the course line as drawn on the photograph will be so close to its true direction as not to introduce any error into the



① K-3B prints ready for radial line plotting. ② Diagrams of K-3B prints, showing procedure of marking.

FIGURE 148.—Preparing photographs for radial line plotting (exercise No. 148).

azimuth plotting. However, the methods of *a* above should be practiced until a substitute center is seldom needed.

(6) All ground control points are transferred to adjacent photographs and surrounded by a small, equilateral triangle. To avoid marking long names, ground control points may be given a roman numeral.

(7) Wing points, right and left, are necessary in the radial line and templet methods. These are clearly defined points of detail lying in the small overlap common to every three successive photographs, and at a distance from the principal point about equal to the distance the transferred principal points or the substitution centers of the adjacent photographs lie from the center of the photograph. These points are pricked and marked with a short dash approximately normal to a radial line from the center of the photograph, 1–2, 1–3, 2–2, etc. If clearly defined points of detail have been selected, they are easily transferred to the adjacent photographs, 1′–2, 1′–3, 2″–2, etc. If the plot is to include several strips, it is desirable that the wing points should serve also as tie points between strips. In that case three strips should be worked up concurrently, selecting and marking both wing points on the middle strip and the same points on the two adjacent flights.

(8) Radial lines, for the radial line method (par. 78), are drawn from the principal points, whether substitute centers are used or not, through all wing and ground control points. Only about ½ inch of the ray is drawn on either side of the point. A convenience for this purpose is a special straightedge of celluloid (fig. 149). *H* is a fine hole for No. 10 needle drilled exactly on line with the ruling edge. This ruling edge should be beveled underneath to permit the use of a crow quill pen in drawing rays.

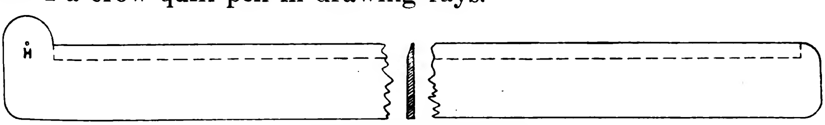


FIGURE 149.—Radial line rule.

(9) Auxiliary control points, wherever needed, may now be selected and marked as, 1–4, 2–5, etc., and transferred to adjacent photographs, marked with dashes and the rays drawn in blue or green ink. These marks should not be in the usual red or yellow as they have no part in the photographic control in either the radial line or templet methods. The auxiliary points are of use only in the compilation (sec. XVIII), for the purpose of correcting relief distortion or accurately locating important road junctions or other prominent features of topography.

d. Exercise No. 27: selecting points and marking photographs.—In accordance with the instructions in this paragraph and with the data furnished, select, mark, and transfer all points, and draw the necessary lines to prepare a set of photograps for making a radial line plot (fig. 148).

e. Additional points for 5-lens composites.—(1) In paragraph 74*b* (1), it was stated that the components of the composites are left unmounted so that the stereoscope could be employed in transferring the several photographic control points. The center B prints are marked in the same way as single verticals in *c* above. The substitute centers are more generally used with 5-lens composites, for the reason that these points are also transferred to the preceding and following D and E prints on which they appear clearly enough to be identified. This has the effect of materially increasing the stiffness of the plotted azimuths. Two or three points along the center of each A and C print are selected, marked, and transferred to the adjacent A and C prints (fig. 150). The side lap with the T-3A camera is usually 55 percent or more. If more than one strip is to be plotted, the A and C points about halfway to the center of adjacent strips should be tie points, common to both strips. Selection of wing points beyond the tie points is unnecessary, except that the principal points of B prints of the adjacent strip should always be marked wherever they can be accurately identified. In selecting auxiliary control points on the wings preference should be given railroad crossings, turns in the shore line, and similar places so as to furnish exact locations for important detail, and at the same time to divide the photograph into small areas seldom more than 2 inches across to furnish a convenient framework for adjusting and tracing intermediate detail later on.

(2) Radial lines are drawn after the composites are finally mounted.

(3) Special stereoscopes of the mirror type with lenses to compensate for the long optical distances should be provided if much control work is to be accomplished with vertical composites. The mirrors and lenses are supported in a box-like, wooden frame which runs on short tracks of angle iron supported only at the edges of the table, and about an inch above the table surface, so as to permit freedom in arranging the large mounts beneath the stereoscope. Selecting, transferring, and marking points after the components are mounted saves time and aggravation, and the results are more accurate.

(4) Mounted nine-lens composites from the tandem T-3A cameras are now being utilized for the templet method. The components are usually printed on a pigmented, topographical film-base stock. The mounting must be done with the utmost accuracy, as the composites are treated as single verticals in marking and preparing the templets.

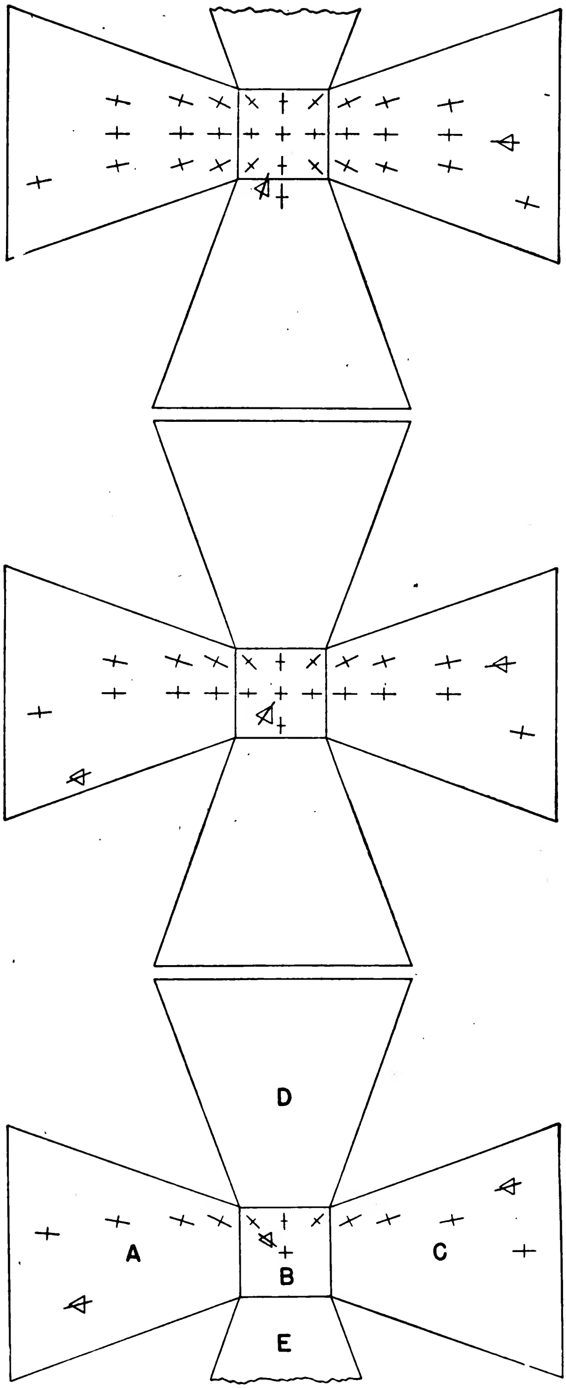


Figure 150.—Diagram of first three composites prepared for radial line plottings.

SECTION XVI

PHOTOGRAPHIC CONTROL AND ADJUSTMENT METHODS

76. Reconnaissance method.—*a*. This method (fig. 151) may be used for constructing a reconnaissance strip or mosaic map from photographs overlapping only 25 to 50 percent. After the principal point of each photograph has been marked with a small cross and numbered, the photographs are assembled, each strip in numerical order. Two common points of sharply defined detail, *a* and *b*, are selected on each pair of overlapping photographs, pricked accurately, and circled. These points must fall in the overlap, as far apart as practicable, and close to the line between the principal points, when the overlapping portions of the photographs are superposed.

b. To plot the control, place the first photograph under the lower end of a piece of transparent material of suitable size, and trace the point *a*; mark it *a–1*, dot the point *b*, and accurately draw a fine, straight line from *a–1* to *b*, and a little beyond. Replace the first photograph with the second so that the point *a* on the second falls under the point *a* traced from the first and the course lines coincide. If the point *b* on the second photograph falls in the same position as *b* traced from the first, its position is regarded as correct and the point marked *b–1*. If the two positions of *b* do not coincide, mark a point halfway between its first traced position and its position on the second photograph, circle, and mark this new point *b–1*. Repeat this process until the points of all photographs have been traced. The result will be a tracing as shown at the right in figure 151.

c. Orientations must be made with all possible care. This necessitates that, both on the photographs and on the tracing, dots and lines must be fine and accurately placed. It will be seen that the orientations are made, as accurately as the limited overlap allows, in accordance with the radial line method of orienting (par. 78), but that distances can be obtained only approximately, for distortions of tilt and relief and changes of scale of photographs, due to variation of flight altitudes, are not corrected. However, a fair, plane map of comparatively flat country, quite suitable for the hasty maps described in section VIII, can be traced from the photographs.

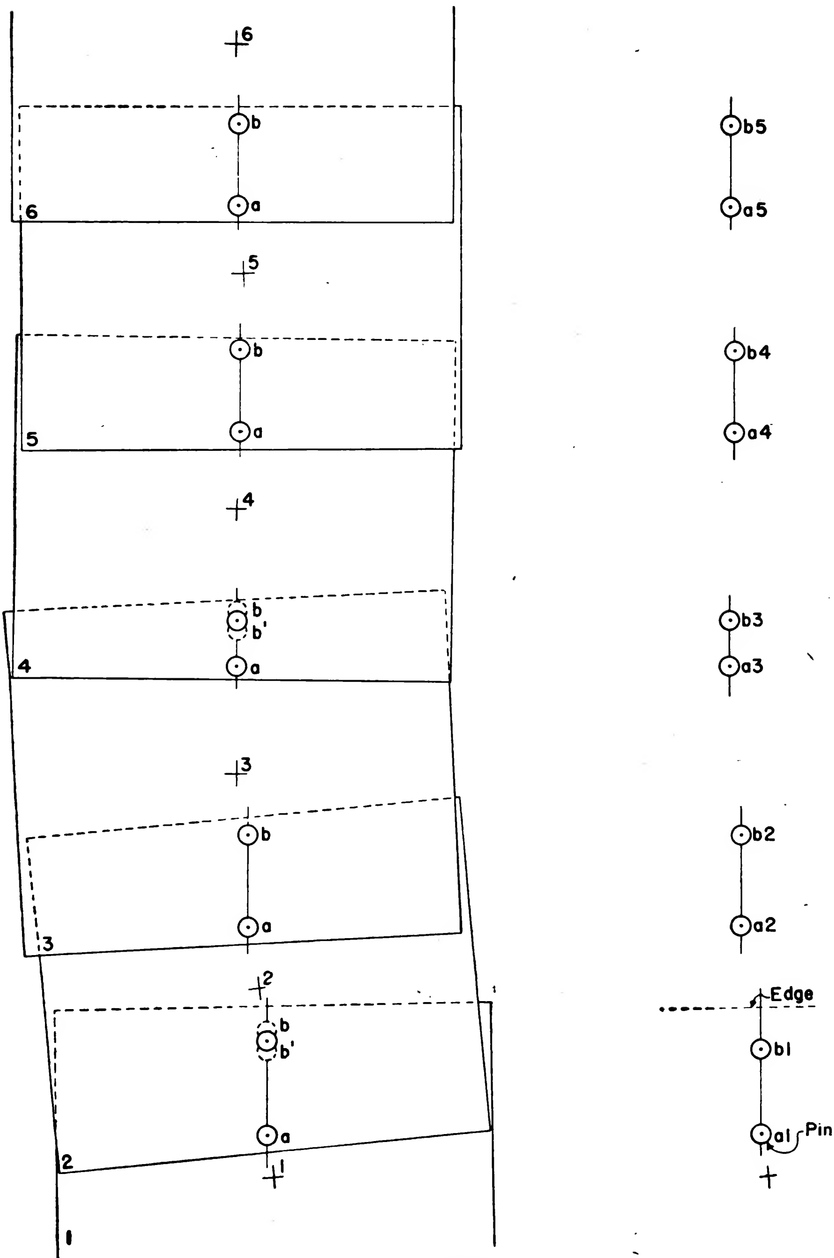


Figure 151.—Reconnaissance control.

77. Center-to-center method.—*a.* This method may be used for the same purpose as the reconnaissance method (par. 76), provided the photographs overlap more than 50 percent; also it may be used to orient and adjust several photographs of a strip and then trace the planimetric detail from them to serve as a skeleton map or plane table sheet. After the principal point of each photograph has been marked with a small cross, select an object or feature very near the marked center, preferably on the course line, and mark and label. These points must be suitable for identification on the adjacent overlapping photographs on which they are also marked and labeled. Each photograph should now have three points marked on it, its substitute center and the two substitute centers transferred from the adjacent photographs. The center lines are then drawn from the center point straight through the transferred points to the edge of the print, and a "tick" is marked at the opposite edge before the straightedge is moved. No wing points are used.

b. (1) To plot the control, orient the first photograph, as (7) in figure 152, under the lower end of a piece of transparent paper, etc., of suitable size, and trace the center point 7–1, dot the point where the center point 8–1 of the next photograph registers on the first photograph (7), and draw in the course line from 7–1 to 8–1, and a little beyond where the forward edge of the next photograph will fall. Replace the first photograph (7) with the second photograph (8) and shift the tracing until the center point of the first photograph 7–1, as registered on the second photograph (8), falls under the center point 7–1, traced from the first photograph (7), and the course lines on the photograph and tracing coincide. If, in this position, the center point 8–1 on the second photograph coincides with the point 8–1 traced from the first photograph, its position is accepted as correct and the point is circled and marked 8–1. Should the two points not coincide, a point halfway between them is selected, dotted, circled, and marked 8–1. The center point of the next photograph 9–1 is then traced (dotted) from the second photograph (8) and the course line, 8–1 to 9–1, just beyond the edge of the third paragraph, is drawn in. The second photograph (8) is now replaced under the tracing by the third photograph (9) and the procedure described above repeated, and so on for each photograph until the traverse of the entire strip is plotted. This will result in a tracing of a series of lines joining center points, as shown at the right in figure 152.

(2) A mosaic may now be constructed by transferring the traverse onto a sheet of heavy mounted paper and pasting the photographs in proper relation along the traverse, proceeding as described in para-

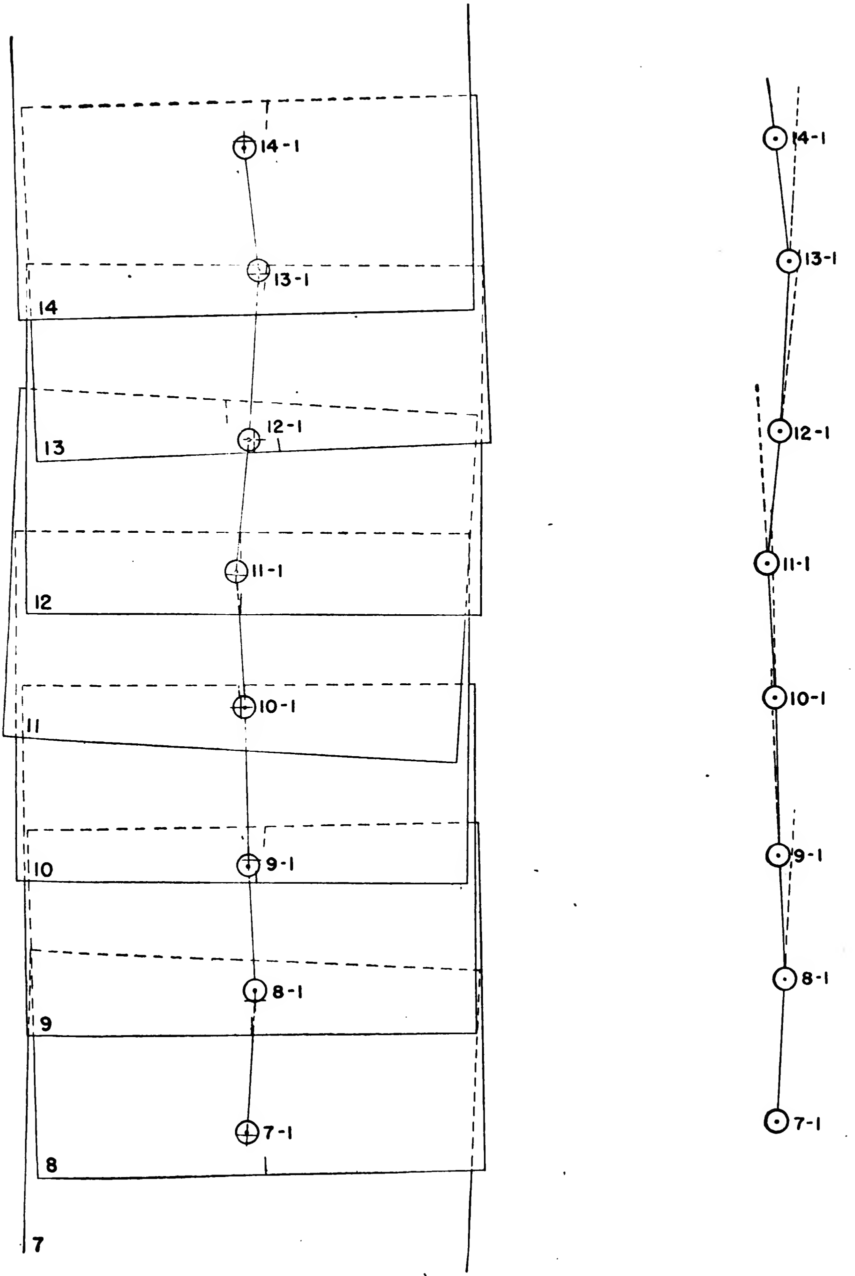


FIGURE 152.—Center-to-center control.

graph 42. The finished mosaic may then be reproduced at any desired scale, or the planimetric detail may be traced directly to supply the necessary data for a skeleton map or plane table sheet. While the results obtained with this method are superior to those of the reconnaissance method, the radial line or templet method (par. 78 or 79) should be used whenever photographs with more than 50 percent overlap are available.

78. Radial line method.—*a. General requirements.*—Excellent flying is the foundation for the radial line and templet method (par. 79). Straight, parallel flights on an even keel and at constant altitudes reduce the tilt and provide the required overlap coverages without reflights. Straight, even flying enables the photographer to maintain a vertical camera axis and to eliminate unwanted crab. Photographic technique and laboratory skill combine to register all available detail clearly and distinctly over the entire surface of the photographic print. Good photography speeds up map preparation and makes possible the extremely accurate plotting of detail, so desirable on military maps. The draftsman has his part. Several years' tests with identical sets of photographs have demonstrated that the comparative accuracy of the results of radial line work can be predicted from a knowledge of the relative skill and care exercised by the draftsmen in all of the steps, from pricking points through drawing rays to the final inking-in of the detail. Judgment and experience help, but they are gained more rapidly by the man possessing keen eyes and steady hands. The finest lines which can be drawn without unduly slowing up the work should be used when tracing the radial lines, in order to keep the graphic errors as small as possible.

b. Principles.—The principles of the radial line and templet methods (par. 79) follow:

(1) Relief displacements are radial to or from the plumb point.

(2) Tilt distortion is radial to or from the isocenter.

(3) With the camera axis vertical, plumb point and isocenter are at the principal point.

(4) It is assumed that rays from the principal point contain the correct position, provided that tilts are less than 3° and elevation differences are less than 10 percent of the net plane altitude.

(5) The position of the principal point can be resected from three photograph points which have been plotted.

(6) When two overlapping photographs are oriented with their principal points in the plotted positions, radial lines through images common to the photographs will establish the position of such images [at th]e intersection of the radial lines.

(7) Thus, by intersection, positions of two wing points for the succeeding photo are fixed.

(8) In resecting for the position of the next principal point, the course line of the photograph must coincide with the same line already traced.

(9) As the photograph position of a point some distance from the center is rarely the same as its map position, the entire area to be mapped must be covered by overlaps.

c. *Purpose.*—The purpose of these methods is to extend control and increase the density of control points to provide a close network of points about which photographic detail may be accurately plotted.

d. *Summary of steps.*—A summary of steps for surveying by the radial line method follows:

(1) Marking photographs (par. 75).
(2) Plotting photographic control strips.
(3) Determining mean scale of all strips.
(4) Preparation of projection (par. 59 or 61).
(5) Plotting ground control on projection (par. 68).
(6) Adjusting all principal points and wing points to projection.
(7) Plotting wing and auxiliary points on projection.
(8) Tracing detail from photographs (par. 87).

e. *Plotting to scale of first two photographs.*—(1) This is the usual military procedure, because an ideal distribution of horizontal control is seldom attained. The mean of the first principal point distance on the first two photographs to be plotted in each strip is assumed as correct for that strip. Lay out the prints of the strip in order, with the overlapping detail superposed. Over the photographs lay a piece of transparent material (*k* below) of suitable size, and mark on it two corners of the first photograph to be plotted. By this procedure, running the plot off the edge is avoided.

(2) Fasten down the first print of the series shown in figure 148 and secure or weight the tracing material over it as indicated by the corner marks. As in figure 153, prick, dash, and number the point 1; lay a straightedge alongside the tick at the rear edge of the print and the course line 1–2, extending same to a total length about equal to the width of the print, and dot the point 2″ (fig. 148②) on this line with a sharp pencil. From the point 1, carefully trace the short radial lines through 1–2, 2″–2, I, 2″–3, and 1–3. The dash at the point 1 should be about 0.1 inch long and about normal to the course line but need not be broken. Replace the first photograph with the second (2), placing the traced point 1 over point 1′ of the photograph, and the traced course line 1–2 in coincidence with that of the photo. Dot

[illegible] the two dots coincide, prick, dash, [illegible] the dots are separate, prick, dash, and [illegible] between them. Move the tracing so that [illegible] photographic point 2 and the traced [illegible] holding the tick at the for- [illegible] in coincidence, and trace the [illegible] beyond the edge of the next [illegible] From point 2 trace rays at all [illegible] photograph (2). Points [illegible] of the scale of the [illegible] The radial lines to [illegible] direction lines only. [illegible] points are [illegible] for the purpose of [illegible]

[illegible] the tracing with the last [illegible] Maintaining [illegible] line until the [illegible] pass through [illegible] the tracing in [illegible] from point 3 [illegible] radial lines [illegible] 3). [illegible] photograph

[illegible] of [illegible] at [illegible] scale. [illegible] are

[illegible] the [illegible] of the [illegible] posi- [illegible] of [illegible] photographs. [illegible] due [illegible] photo- [illegible] passes as [illegible] line on [illegible] Trace [illegible] small balanced

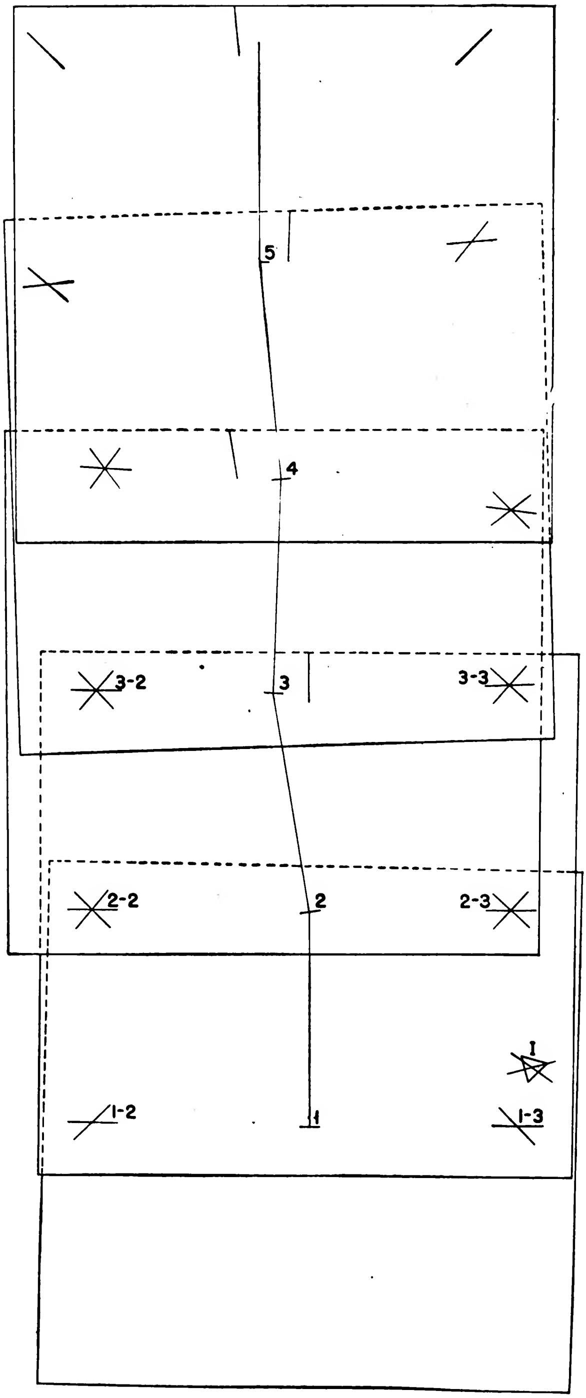


FIGURE 153.—Plotting to scale of first two photographs (1 and 2).

the point 2 on the traced line. If the two dots coincide, prick, dash, and number this as point 2. If the dots are separate, prick, dash, and number a point 2 halfway between them. Move the tracing so that adjusted point 2 falls over the photographic point 2, and the traced course line is in coincidence throughout, including the tick at the forward edge. Secure the tracing while in coincidence, and trace the course line 2–3″ long enough to extend beyond the edge of the next photograph but do not dot point 3″. From point 2, trace rays at all wing and ground control points shown on photograph (2). Points 1–2, 2–2, 2–3, I, and 1–3 have thus been intersected at the scale of the base line 1–2, which is the scale of the tracing. The radial lines to 3–2 and 3–3 and the base line 2–3 are, at this stage, direction lines only. In practice, only the principal points and ground control points are numbered. Here the wing points are numbered for the purpose of explanation.

(3) Place the third photograph (3) under the tracing with the last traced course line over the photograph course line 2′–3. Maintaining complete coincidence, slide the tracing along the course line until the radial lines through 2′–2 and 2′–3 on the photograph (3) pass through the intersections at 2–2 and 2–3, respectively. Secure the tracing in this position; prick, dash, and number the point 3; from point 3 trace the advance course line through the point 4″, and radial lines at all the wing and ground control points shown on photograph (3). Continue the process just described for each remaining photograph of the strip.

(4) It is clear that this method of plotting strips is independent of the position of ground control points. In fact some of the strip plots may not cover a single control point. So long as all were flown at the same altitude, the scales of the strips will be about the same, and strips lacking ground control can be adjusted to those which are controlled.

f. Triangles of error.—Occasionally in spotting a photograph the two wing radial lines (to the left and right of the center point of the preceding photograph) will fail to pass through the intersected positions of these points on the tracing. This usually indicates errors of draftsmanship, or careless marking of points on the photographs. Should this condition still persist after checking, it is probably due to combined tilt and relief, and may be adjusted. Shift the photograph along the course line until the radial line on one side passes as far above the intersected position of its point as the radial line on the other side passes below the intersected position of its point. Trace the radial lines in this position which will result in two small balanced

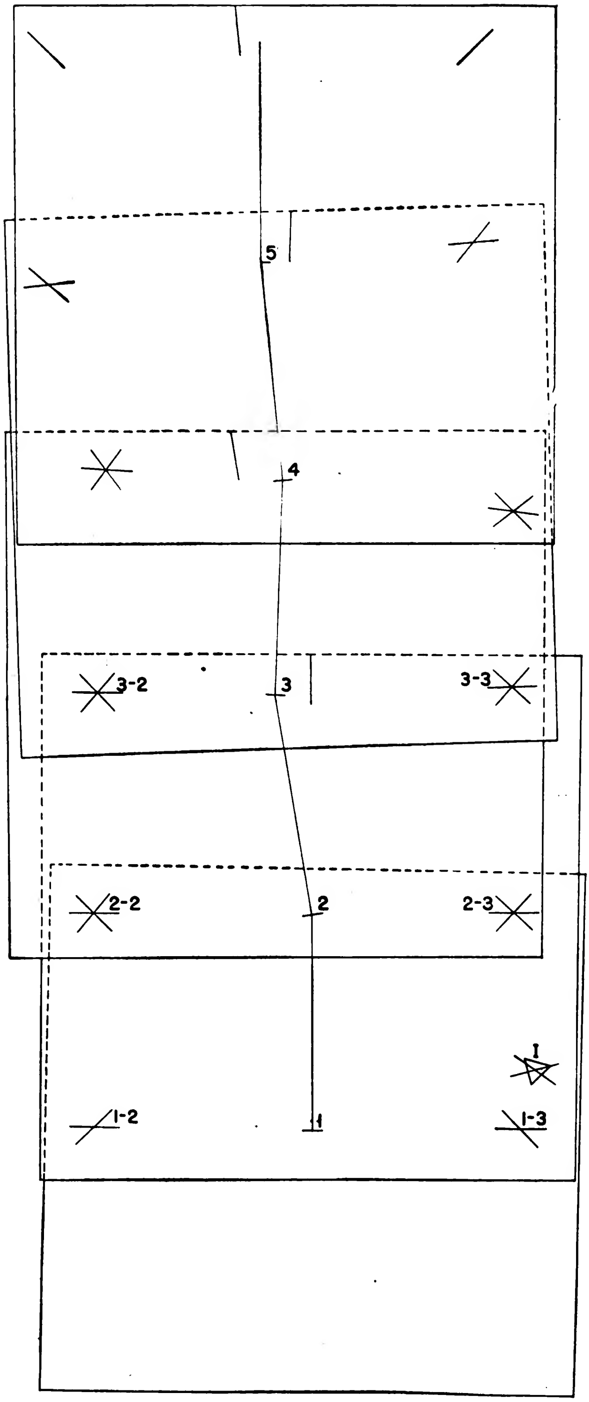


FIGURE 153.—Plotting to scale of first two photographs (1 and 2).

triangles of error on the tracing, the centers of which may be considered the true positions of the corresponding wing points. Careless marking of points on the photographs, inaccurate plotting, and failure in maintaining exact coincidence of course lines at all times are the three chief sources of error with the radial line methods.

g. Insufficient overlap.—Occasionally the overlap between adjacent prints may fall below 50 percent. Substitute center points may then be selected near the edges of such prints and near the principal point base lines. Figure 154 represents the treatment of an example in which photographs (4) and (6) do not meet. Points 4_3 and 4_5 are the substitute centers. Points of detail m_3 and m_5 are chosen in the 3–4 and 4–5 overlaps as close together as possible, and at the same elevation, as nearly as can be determined with the stereoscope; n_3 and n_5 are chosen in like manner. Radial lines are drawn on the prints from principal points 3, 4, and 5. Photo (4) is oriented as usual on the course line 3–4_3, and all radial lines are traced, and the photograph positions of m_3, m_5, n_3, and n_5 are dotted on their rays. The strip positions of m_3 and n_3 are intersected at m'_3 and n'_3. The line m_3–m_5 is drawn on the tracing, and a parallel line from m'_3 cuts the m_5 ray at m'_5 which is the strip position of m_5. The strip position of n_5 is similarly plotted at n'_5. Photograph (5) may now be resected from the course line 4_5–5 and the wing points m'_5 and n'_5.

h. Plotting to selected scale.—(1) This method is used when it is desired to plot the photographs directly to the scale of the field sheets which may differ somewhat from that of the photographs. Three points of horizontal ground control falling in the overlap between the first two photographs of each strip are essential to the method. These points should be well distributed across the transverse field of the photograph to provide good angles between the radial lines at the center and strengthen the three-point orientation of the first two photographs of the strip. The orientation of the first two photographs of a strip fixes the orientation of the strip. The scale at which the ground control has been plotted fixes the scale of the photographic control.

(2) Merely as a matter of illustrating this variation, the course lines in figure 155 have been drawn between substitute centers, and the radial lines have been drawn from the principal points. The latter are preferred for all purposes, if they can be accurately transferred to adjacent photographs.

(3) In figure 155, broken triangles and circles represent points plotted on the photographs, solid triangles and circles the plotted position of corresponding points on the tracing to the selected scale. With the three ground control points I, II, and III plotted on the tracing,

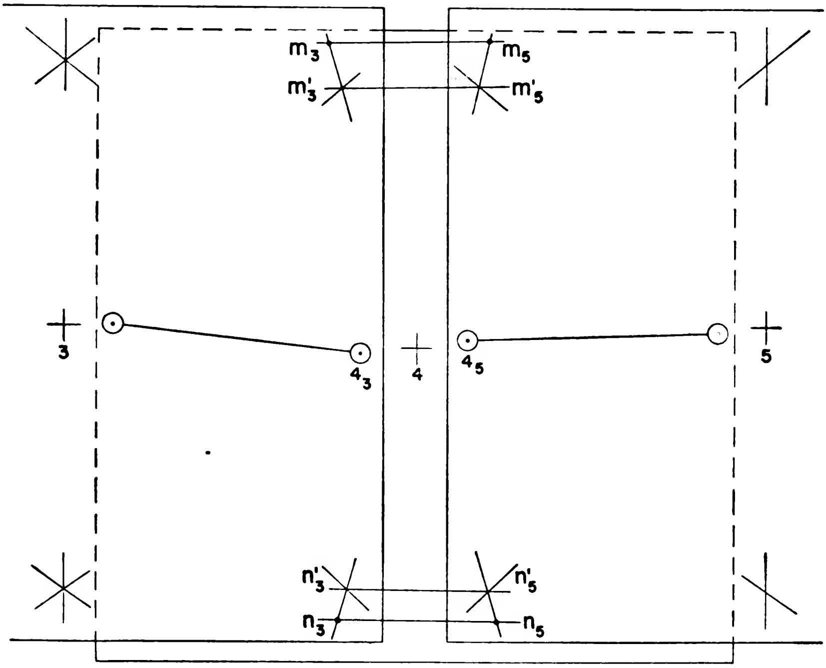


FIGURE 154.—Plotting with less than 50 percent overlap.

orient the first photograph (9) and shift until the plotted points I, II, and III fall on their radial lines on the photograph. Trace the substitute center 9-1 and the course line 9-1 to 10-1, prolonged to a length about equal to the width of the print; trace the principal point 9 and the radial lines therefrom through all points marked on the photograph (9). Replace the first photograph (9) by the second photograph (10), orient same by the three plotted points I, II, and III in the same manner as the preceding photograph, finally checking to assure that the previously traced course line is in coincidence with the course line 10-1 to 9-1 on the photograph. Trace the substitute center 10-1 and the course line 10-1 to 11-1 as before; trace the principal point 10 and from it as a center trace rays at all points marked on the photograph (10). Two of the radial lines through 10-2 and 10-3 will intersect the radial lines through these points traced previously from the preceding photograph (9), these intersections establishing the position of 10-2 and 10-3 on the tracing at the changed scale. Replace the second photograph (10) by the third photograph (11) so that the course line on the tracing coincides with the course line on the photograph, then shift the tracing along the course line until the two previously estab-

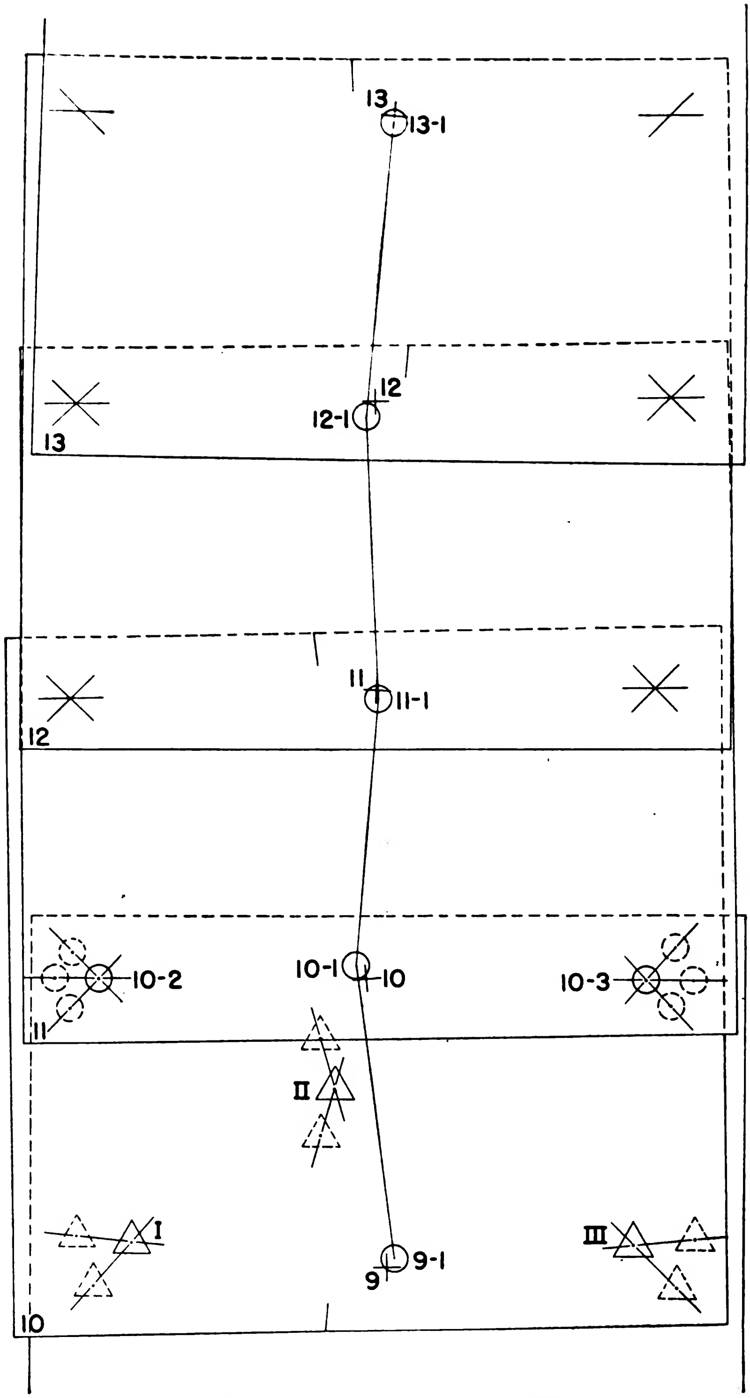


FIGURE 155.—Plotting to selected scale.

lished positions 10–2 and 10–3 fall on their radial lines of the photograph (11). Trace in the center point 11–1 and the new course line, and the principal point 11 with the rays at all wing and ground control points marked on the photograph (11).

(4) Continue this process for each remaining photograph of the strip, plotting additional ground control points similarly whenever they appear on the photograph. When plotting an area several strips of photographs in width, all strips may be plotted at the same time, alternating between strips, plotting three photographs of each strip at a time. Adjustments are made whenever a point of known position, usually a ground control point, is picked up. If the error at the ground control point is very small, it may be adjusted by repeating the work with more care. If an investigation of a larger error shows no isolated cause, that part of the strip may have to be adjusted by the method explained in *n* below.

i. Inspection of strips.—(1) As the strips are completed, they should be carefully inspected by the draftsman who will adjust them to the control sheet. The lines must be fine and exactly through the pricked points. The wing points should be sharp, three-ray intersections, and the fineness of the crossing is a check on the reliability of the plotting. Any triangles of error or short course lines should be investigated. A few of the photographs selected at random should be oriented under the tracing and the accuracy of the plotting checked.

(2) If the course lines have been drawn through the principal points, the strip may reveal the quality of flying. A sudden bend at a principal point indicates tilt. A principal point base line longer than average is a sign of tip, provided the difference is not due to relief distortion. From such factors, the experienced draftsman may evaluate the relative reliability of the strips.

j. Determining average scale of strips.—Some of the strips will doubtless contain two or more ground control points. If not, the strip distance between control points may have to be scaled after two or more strips are temporarily joined by superposing their common tie points. The plotted strip distance divided by the computed ground distance (both in the same linear units) will give the representative fraction of the strip. An average RF scale is obtained by taking the mean of the denominators of the strip RF's. This value is more reliable than one obtained by the methods of paragraph 28. The nearest RF whose denominator ends in 500 or 000 is taken as the scale of the projection sheet. A close agreement between the scales of projection and photographs markedly increases the quality and speed of plotting the details. (See sec. XVIII.) The disparity in scales should never exceed 5 percent.

k. Material for projection sheet.—(1) Because the projection sheet is employed as a base to which the strips are adjusted, and so becomes the adjusted control sheet on which the planimetry is traced directly from the photographs, the material must be transparent. Nonshrinkable, topographic film base, 0.006 to 0.008 inch thick, light matte on one side, is most suitable. Tracing cloths and papers are too changeable in scale and not transparent enough for work with photographs. However, if the film base is not available, Post's No. 167 ivory-white tracing paper or its equivalent is the most suitable of the cloths or papers. The film base comes in 100-foot rolls, 40 inches wide, and is quite expensive. Every precaution must be taken to keep the stock unimpaired and to avoid waste. The rolls should be wrapped in several thicknesses of tissue paper and kept in metal map tubes. While fresh material should always be used for work which is to be inked, second-hand pieces from which the previous work has been washed will often do for templets, strip plots, etc. If the matte surface has to be restored, powdered pumice on a cloth pad should be applied with a brisk, circular motion. This is not an economical procedure, as regraining a 40- by 60-inch sheet will take several hours. If the work is more than 40 inches wide, two widths can be joined with small patches along the edges applied with film cement.

(2) The film base does not take ink readily. Several special celluloid inks are sold, but all are more difficult to apply than the best black drawing ink. The latter has the advantage that it can be erased with a damp cloth, leaving the surface ready to receive more work. Film base sheets should be handled only by the edges. It is very important to keep grease from the fingers and dirt from the sheet as far as practicable. Some draftsmen have trained themselves to touch the sheet only with their finger nails or with a stylus, and to rest their pen hand on a light board such as a cigar box lid supported by small pieces of rubber glued to its bottom. Other draftsmen use white cotton gloves. Still others have several sheets of paper with which they keep the sheet covered except where they are working. If the sheet does become somewhat greasy and refuses to take ink well, a good rubbing with powdered pumice or tracing powder helps considerably. As the ink has a strong tendency to chip off, the sheets should be handled carefully and the inked portions should be covered with several pieces of soft tissue paper.

(3) The projection may be drawn in pencil on the celluloid sheet. This must be done if the draftsman is not familiar with such work. Care should be taken not to scratch the sheet or puncture holes unnecessarily as such abrasions cause the ink to run and spread. A 2H or

3H pencil will show quite strongly on the matte surface. The penciled work should be checked for accuracy, then inked and checked again. No errors in excess of 0.01 inch should be accepted in the plotting of the control. Pencil marks may be removed with art gum.

l. Projection sheet.—The projection sheet may be the polyconic (par. 59) with grid superposed or the standard military grid (par. 61) with meridians and parallels added. The latter is more convenient, as a grid may be traced repeatedly in any location provided the scale is the same.

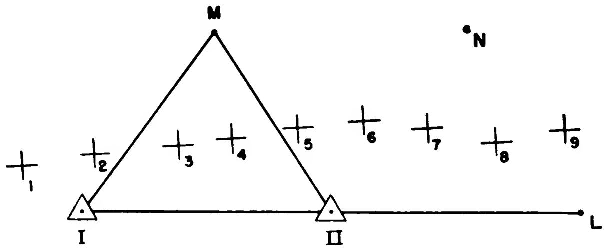
m. Ground control points.—These are plotted by the methods of paragraphs 67 and 68. When the control has been checked for accuracy, it is well to ink it in blue on the reverse side of the sheet. This retains the position but does not interfere with the drafting. The proper symbol can be inked on the upper surface when it will no longer interfere with the compilation.

n. Adjusting strips to projection.—(1) A strip covering two control points at some distance apart could be adjusted to scale and replotted to the control sheet by one of the methods described in paragraph 22, FM 21-35. That procedure requires tracing, replotting, and tracing, in addition to a graphical determination of errors, and affords no independent check on the readjusted positions.

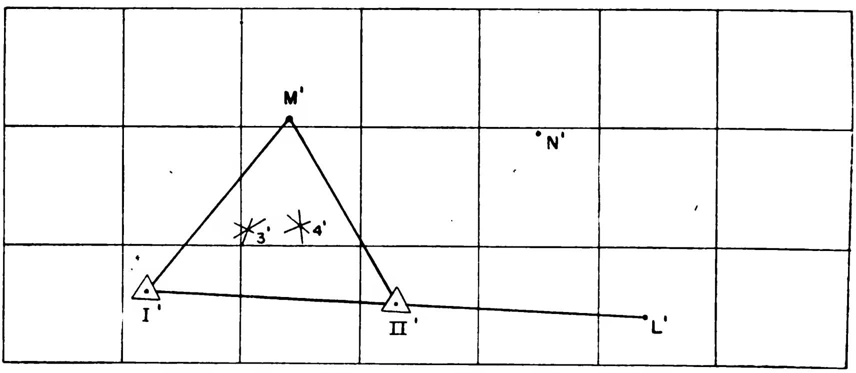
(2) Figure 156 ① shows principal points 1 to 9 of a strip on which ground control points I and II have been identified and plotted. The wing points are omitted in order to avoid confusion. In figure 156 ② I′ and II″ are the same two ground control points plotted on the projection or control sheet. In order to reduce the length I–II to the length I′–II′ and to plot the traverse to the same scale, select a point M about in the position shown, fulfilling the conditions of (3), below. Draw I–II, I–M, M–II, and I′–II′. Place the control sheet over the strip so that I′ is over I, and I′–II′ coincides with I–II. Trace the ray I′M′. Place II′ over II and orient by the line II′–I′, and draw II′–M′, thus locating the position of M′. The triangles I–II–M and I′–II′–M′ are similar. To plot the adjusted position of the point 3, for example, with II′ over II and the adjacent sides of the triangles in coincidence, draw a part of the ray over the point 3. Similarly, draw rays from I′ and M′. Point 3′, at the intersection of the three days, is the adjusted control sheet position of the point 3. Other principal points and wing points may be intersected at the same time.

(3) Any similar triangles will serve, provided the scale ratio is maintained. A sharp, three-ray intersection must be obtained for every point. At least two of the rays should intersect at not less than about 60°. Points 7, 8, and 9 could not be accurately intersected from

the three points previously used. In such case select a new auxiliary point at N; if necessary extend the line between the ground control points to twice or any other multiple of its length, as at L. To avoid waste of material, the strip sheets are usually narrow and the triangles have to be arranged to fit. Figure 157 shows a control sheet completed except for auxiliary points.



① Radial line strip to be adjusted.



② Control sheet—adjustment of strip partially completed.

FIGURE 156.—Adjusting strips to projection.

(4) The foregoing method of adjusting strips to control sheets can more easily be adapted to varying density and disposition of ground control than can the method suggested in (1) above. The many different arrangements may be represented by four general cases, in order of difficulty, as follows:

(*a*) Fully controlled.
(*b*) From control to uncontrolled territory along strips.
(*c*) From control to uncontrolled territory across strips.
(*d*) No control.

The results from (*b*) and (*c*) will be more reliable if a few points can be intersected from accessible territory; (*d*) would have to be worked out at an assumed scale. Tie strips, flown at right angles to

the others, may be provided near the ends of the parallel strips, if remote from ground control. In any case, a small diagram showing the strips and the control points will indicate where to commence. The final plan must take all available data into consideration. While

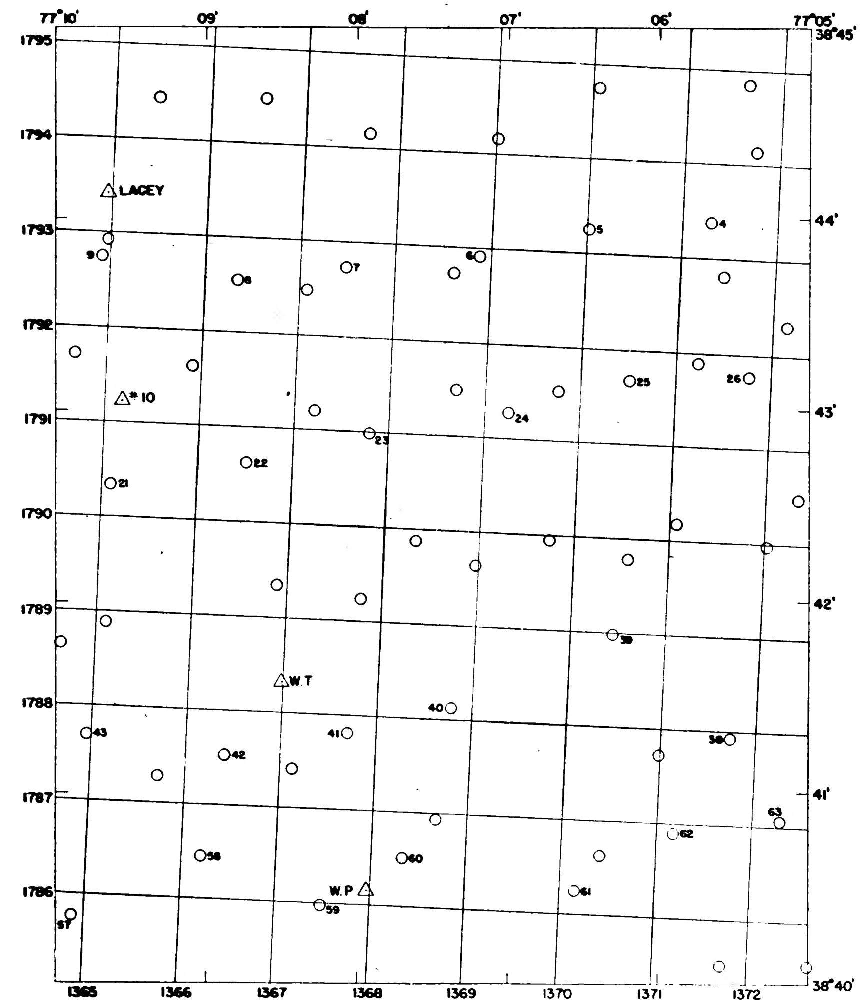


FIGURE 157.—Adjusted control sheet same as figure 137, exercise No. 25, with photographic control points added (exercise No. 28).

the control points must remain fixed, the photographic control points have to be brought into correct relation with them. Sometimes quadrilaterals offer a better solution than triangles. The four-ray intersections will not always be sharp, but the best position in proportion to

the lengths of the rays can be plotted. In that way the area within the quadrilateral is least distorted and still is in fair agreement with adjoining areas.

o. Points on control sheet.—If the wing points are also tie points (par. 75*c*(7)), they will be found in rows between the lines of principal points. Some adjustment may be necessary for the final location of these tie points where they do not agree between flights. If the difference in location exceeds 0.1 inch, the transferring of the points, and the drawing and tracing of rays should be checked. The last can be done by placing the control sheet over the photographs, superimposing the center points, and orienting by the course lines. At this time the auxiliary points are transferred to the control sheets and circled in blue. The principal points and wing points are circled in black and the former are numbered. If the control sheet is to serve as the compilation sheet, the circles should be inked on the back, from which they may be washed after the compilation is finished.

p. Tracing.—The completed tracing is covered with construction and adjusting lines. A fair tracing of this control sheet should be prepared for the purpose of receiving the detail from the photographs. On this copy all of the control points should be inked on the under side so as not to interfere with the compilation. The original should be preserved as a matter of record and perhaps as a basis for the preliminary adjustment of the compilation.

q. Composites.—The broad coverage, the increased conic displacement, and the relatively short principal point bases cause some changes in radial line practice with composites from such work with single verticals. The side lap is increased to 55 or 60 percent, which eliminates the outer portions of the wings where the distortion is worst, and strengthens the tie between flights, as the center points appear on the wings of the adjoining photographs. In laying out a control sheet for a radial line plot, allowance must be made for the photograph control points which may have to be plotted outside of the borders of the area to be mapped. The azimuth is held very rigidly, as the center points appear on so many fore and aft wings of the preceding and following photographs. The distances in the direction of flight are more uncertain because of the sharp angles of intersection and resection on the wing prints. The extra width of the composites usually includes more ground control points, and plotting to a selected scale is common practice. The composites are better adapted for the plotting of two or more flight simultaneously, since this helps to overcome the weakness in the distance component. Any photograph suspected of excessive tilt is examined at the tips. Such composites may often

be discarded, the data being obtained from those adjoining. The increased coverage and distortion on the wings necessitate the plotting of additional points for rectifying planimetry, even in terrain of low relief.

r. Exercise No. 28: plotting photographic control by radial line method.—On the sheet completed in exercise No. 25 (fig. 137) prepare the photographic control by the radial line method from the photographs furnished, plotting the strips to the scale of the first two photographs. Study *a* to *q*, inclusive, above, and figure 157.

79. Templet methods.—*a. General.*—The employment of ruled and slotted templets will be treated separately. Both are in strict accord with radial line principles. Both are faster, easier, and usually more accurate than the drafting procedures just described. Both permit a division of work besides eliminating or shortening some of the steps. Graphical adjustments are unnecessary, as the templets are brought into true map relation before marking the final position of the photograph control points on the projection sheet is begun. The result is a control sheet free from adjustment lines and rays, suitable for tracing detail directly from the photographs.

b. Preparation of ruled templets.—The templets, about ¾ inch larger overall than the photographs, are of topographic film base described in paragraph 78*k*. The photographs are marked as explained in paragraph 75*c*(2). In turn, secure a blank templet over each photograph. Stick a needle through the film base vertically into the principal point of the photograph, and let it stand there as a guide for the straightedge used in drawing the radial and course lines. (See fig. 158.) Through the circled points on the print trace the course lines from the center to the edge of the templet, with a tick on the opposite edge, but the other rays drawn from the principal point need extend only a half inch to either side of the other points. Extreme care must be taken to insure that the templets accurately record the center angles of the photographs. All these lines may be black, but confusion is avoided by using blue for auxiliary radials, as they are not considered while arranging the templets.

c. Extending control.—(1) As the strips are not plotted separately, the average scale may be obtained by laying out the photographs of each series with the centers superimposed, or using the templets if convenient. The mean RF is determined as usual from measurements between control points. The projection and ground control are plotted as for the radial line method. Plotting to a selected scale is a little more convenient with ruled templets, especially if intermediate control points are available. The mean scale of the first two, or any two,

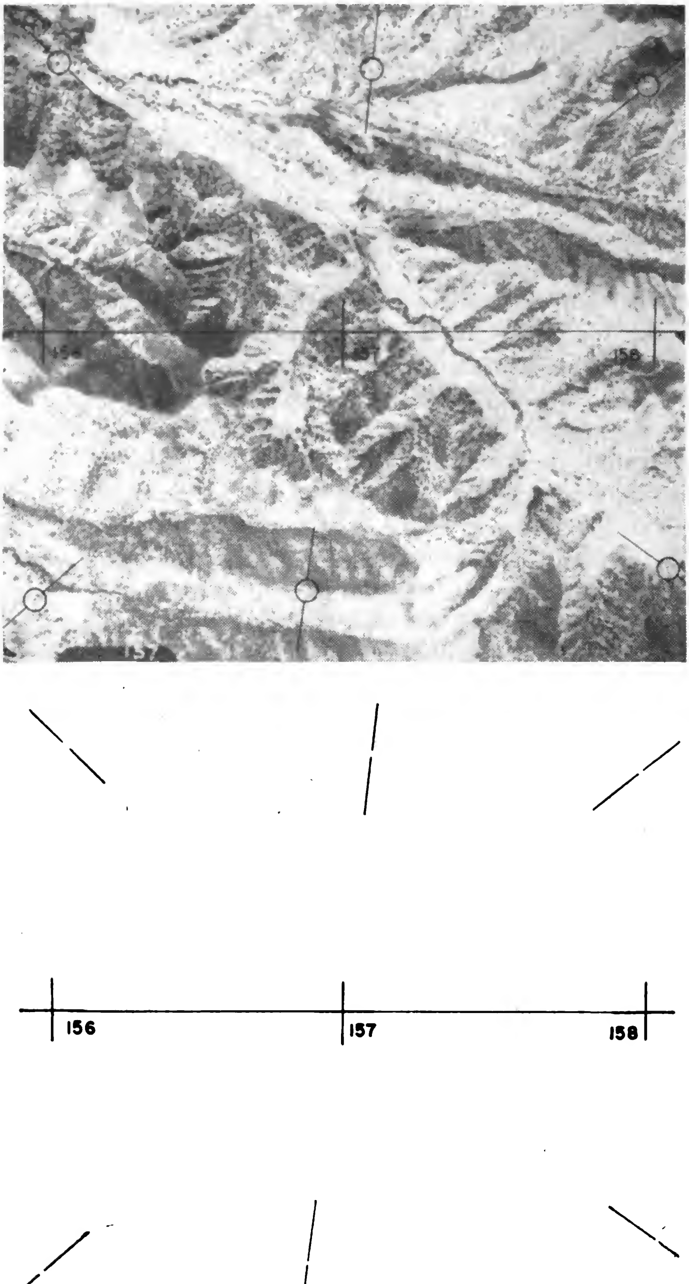


FIGURE 158.—Ruled templet.

photographs may be used. If the scale selected causes an error too large for easy adjustment, reassemble with a slightly changed separation of the first two prints.

(2) For the selected scale method, place the first templet on the control sheet in such a way that the rays on the templet pass exactly through the three plotted points, and secure it in place. The second templet is placed over the first so that the ground control radials pass through the corresponding points on the control sheet, and is then weighted down. In every case the course lines must be kept in exact coincidence. Only by exercising extreme care in this respect can the azimuth of the strip be correctly maintained. The intersecting radial lines represent the map position of the points through which they were drawn on the photographs. The third templet is now adjusted by means of its course line and radials so that each radial line passes through the intersection over the corresponding point as formed by the superposition of the first and second templets. The templets are now fastened to each other with two 1-inch strips of scotch tape near opposite corners. Additional templets are added by twos and threes, weighted, checked, and taped as above. When a complete intersection has been laid to include the next control point, the templet position may check precisely with the control sheet. If not, the draftsman must warp the strip of templets in such a way as to gain the desired coincidence. This way of adjusting the templets between ground control points is much simpler than any drafting method, and sufficiently accurate if all the work has been done carefully and provided tilt and relief errors are not excessive. The amount of adjustment should be so small that all the intersections remain sharp and the course lines in coincidence. After the templets have been adjusted between the initial and intermediate control points, the remainder of the strip is continued in the same way.

(3) After the strips have been assembled and adjusted separately, they are laid together over the control sheet and examined for agreement in the positions of the tie points. Where two strips coincide within the plotable error, they can be joined together with Scotch tape. A small diagram showing the control points and the strips and the areas of greatest error will indicate how adjustments should be made. During this stage the areas affected must be closely inspected to see that the intersections are not broken, that the coincidence of course lines is maintained, and that the templet positions of control points remain fixed. Although the blue inked lines of the templets have been disregarded, sharp intersections wherever more than two of them cross should mark the positions of the auxiliary photograph points.

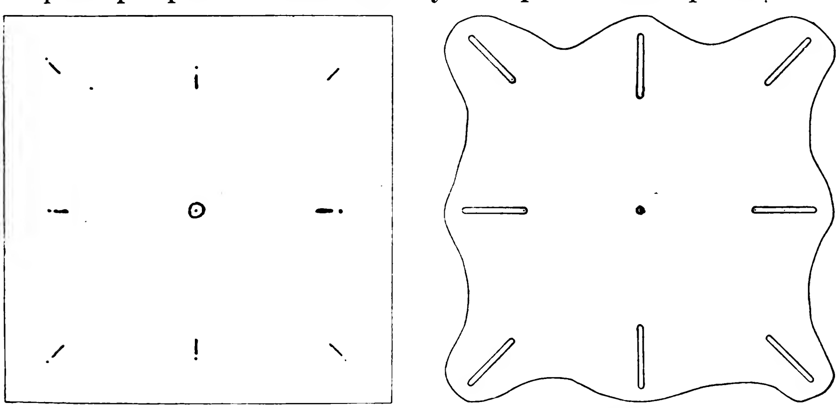
(4) After the adjustment has been satisfactorily completed, all of the center and intersection points are transferred to the control sheet in proper relation to the ground control points already plotted. Probably the safest procedure is to prick the points through the templets to the control sheet without changing the adjusted relations. However, by slipping the control sheet from beneath, and superposing it with the plotted ground control points in exact coincidence with their templet intersections, all of the templet points may be pricked and marked on the control sheet and the principal points numbered directly from the templets. The latter method leaves the templets unpricked, so they may be cleaned and used again.

d. Slotted templet method.—The principal point of each templet is represented by a hole of about 0.15-inch diameter, cut concentrically with the plotted templet position of the point by means of a special hand punch shown in figure 37. Instead of being ruled on the templet, radial lines are represented by slots, about 0.15 wide by 1½ inches long, cut out of the templet by a slot cutter, a simple form of which, weighing about 60 pounds, is shown in figure 36. The cutter is so designed that each slot is formed symmetrically about the plotted templet position of the photographic control point with the longitudinal slot axis on line with the center of the hole representing the principal point. In assembling the templets as described in *g* below, composition or bronze studs (fig. 38) are employed to hold the templets in the correct relation to each other and to the plotted control points. The outside diameter of the stud spindle is in such relation to the width of the slots that the fit is snug without binding, thus permitting the studs to move radially along the slots as the templets are guided to their positions according to the geometrical relations with the adjacent templets and control points. Pins (fig. 38), cut and sharpened from drill rod steel of a diameter to fit the hollow stud spindles without binding or excessive play, are employed to hold the appropriate studs over the correct ground control point positions, and also to plot the control sheet positions of the other studs, after the templets have been assembled and adjusted.

e. Adjustment of slotted templets.—The slotted templets permit a further distribution of labor and the elimination of several steps required by the foregoing methods. Once the photographic control points have been selected and marked on the prints, any careful person can transfer these points to the templets and cut the slots, as these are mechanical operations not requiring great skill or experience. However, actual assemblage and adjustment of the templets should

be performed by the most experienced man available, as these operations while purely mechanical require a nice touch and some judgment. At any rate very little time is required as the relations of the templets are so guided by the fixed positions of the ground control points that they fit together automatically and very little adjustment is possible or necessary. On completion of the adjustment, a few of the studs remote from ground control points are fixed in position by pushing pins through the studs into the control plot and the board, and a junior draftsman can complete the plotting of the intersection points and finish the control sheet.

f. Preparation of slotted templets.—These may be of film base or a good grade of three-ply artist's board. The film base has the advantage that the rays for the auxiliary control points may be ruled on the surface of the templets and the intersections pricked through to the control sheet at the same time as the other points are so marked. The transparent templets are advantageous only in case a great number of auxiliary control points have to be employed. If comparatively few are required, they may be slotted and transferred to the control sheets through studs, as are the wing and principal points. The cardboard has the advantages of being more easily obtained, of being stiffer, and more easily cut and handled. The photographs, marked as in paragraph 75*c*(2), are secured in turn over new templets, and all the points on the photograph are pricked through to the templet with a fine needle. The photograph is removed, the principal point is numbered, and a dash is placed by each point so that none may be overlooked by the operator of the slot cutter. (See fig. 159 ①.) Rays are drawn through any auxiliary points which are not to be slotted. Next, the principal point holes are cut by the special center punch. The



① Marked templet. ② Prepared templet.

FIGURE 159.

guide point is placed in the needle mark, and the hole made by a light tap of the hammer. The templet is placed in the slotter with the spindle of the sliding center through the principal point hole. In turn, the needle marks are brought exactly beneath the guiding point of the cutter and the slot (fig. 159 ②) cut by a single depression of the lever handle. Care has to be exercised, but the slots are cut more rapidly than rays could be drawn. However, if one point is overlooked or a slot displaced, a new templet must be marked and cut. To reduce friction and avoid interference between the templet and neighboring studs, the surplus edges of the templet are usually trimmed off (fig. 159 ②). For large assemblies, templets should be coated with paraffin so as to reduce friction.

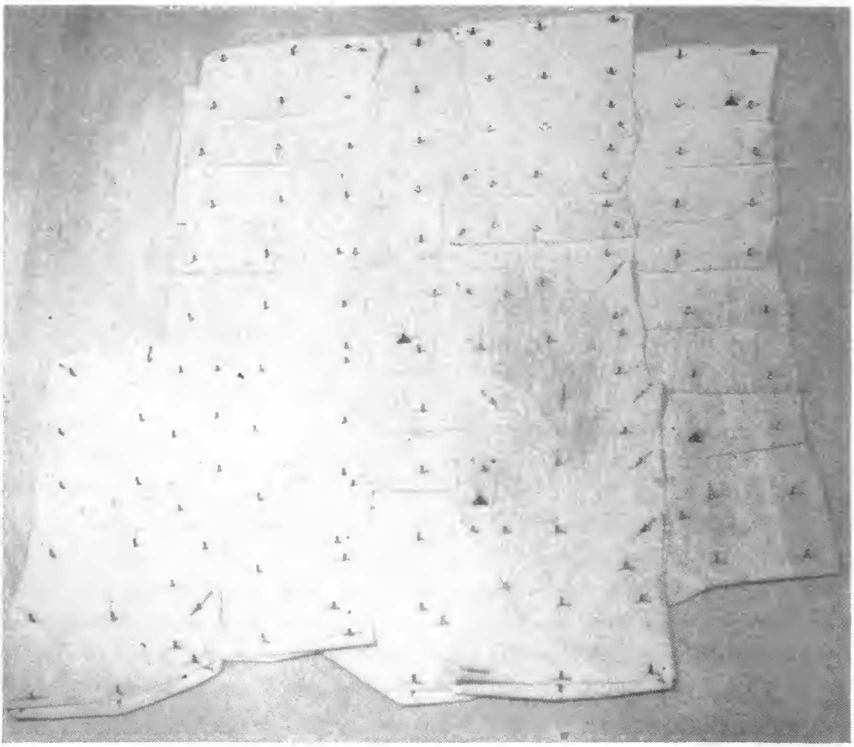


FIGURE 160.—Slotted templets assembled over control sheet.

g. Assembling templets (fig. 160).—The control sheet is scaled and prepared as described in *c* above. It is then placed on a large wooden drawing board. One of the special pins is stuck vertically through each ground control point, and a stud is slipped down over it. Pref-

erably beginning at a control point, a templet is placed with the fixed stud through the slot for that point. Studs are slipped under the templet and through the principal point hole and the remaining slots. The next templet is placed overlapping the first so that the slots to all control points fit on the corresponding studs placed in the first templet. Continue in the same way, usually proceeding first along a line of control points and then outward from the templets already fitted. As the templet assemblage reaches other control points it may be that the studs will fall correctly upon the points already plotted. In that case, leave the control stud pinned in its position and continue with the remaining templets. Quite often, when more than a few templets have been employed in bridging from the last control points, the fit will not be correct. Trial will show that there is a slight give or play among the templets which can be worked gradually in the direction to bring the templets to agree with the plotted point. Absolutely no force or pressure should be used beyond a gentle agitation of the templets, and a taking up of any play, which will be very small, but enough to permit the templets to be fitted to all control points. Occasionally a single templet fails to fit over those already placed so as to fall smoothly into position. Investigation will show that one of the photographic control points has been incorrectly transferred from adjoining photographs or carelessly plotted on the templet, or that an error has been made in cutting the slot. The mistake must be rectified and a new templet cut.

h. Adjustment to control.—If the control is comparatively dense, there will be no adjustment. For a large area bordered all around by control points, it is well to agitate gently the templets in the interior just enough to make sure there is no binding or sticking which might cause a local maladjustment. The adjustment when progressing from controlled into inaccessible terrain is almost as simple as in the last case. Secure a sheet of paper to the control sheet under the templets most remote from control. Commencing near the fixed control gently take up any slight play among the templets in such a way as to tend to compress the assemblage toward the line of established control. Insert a conically sharpened compass lead into several of the studs most remote from control and make a dot under each. The templets are now worked out away from the control and the same studs dotted. The templets are gradually worked first to the right and the same studs dotted, then to the left and the dotting repeated. Removing part of the templets temporarily, it will be seen that an adjusted position for each of the studs concerned can be determined by drawing the diagonals between the opposite pairs of dots for each stud. The

adjustment will be very slight but worth while in promoting the accuracy in those areas. It now remains only to stick pins vertically into the adjusted positions, replace the studs and templets, and test the interior areas to make sure there is no binding.

i. Advantages of method.—The first trial of the slotted templet method will demonstrate its simplicity and certainty as compared with the ruled templets or drafted radial lines. The over-all adjustment is almost invariably less. The results of the adjustment are always more satisfactory since they are made mechanically and as a whole, without risk of disturbing previous adjustments already completed.

SECTION XVII

PHOTOGRAMMETRY AND PHOTO-MECHANICAL MAPPING METHODS

80. General.—Photogrammetry is a general term covering measurements effected from overlapping photographs for the determination of the fundamental survey elements—horizontal distance, direction, and difference in elevation. The radial line plotting of planimetric detail by graphical methods constitutes a very limited step, considering the possibilities of application of aerial photographs to topographical mapping. It serves, however, as an excellent background from which to take up the development of further application. Complete application of aerial photography involves an automatic plotting apparatus from which the operator may obtain both ground plan and contour levels as a direct result of his observations and the setting of the instrument. The development toward this end follows three principal lines: stereo-photogrammetry, restitution by double projection, and a combination of these two.

a. Stereo-photogrammetry.—This covers the subject of photogrammetric measurements made from the stereoscopic restitution of the terrain covered in the common area of overlap.

b. Restitution by double projection.—If the photographs are brought into the same relative orientation as at exposure (or the perspective equivalent obtained), and the direction of the rays that formed the photographs are reversed so as to project the pictures again

into space, then the rays from the same image points of detail must intersect again in space to determine the position of the corresponding object point of detail. Collectively, the aggregate of such intersections will form a model of the landscape at a scale fixed by the spacing of the centers of projection. By properly orienting the model with respect to a horizontal drawing board so that the latter represents the map plane, the orthographic positions of points of detail can be obtained by projection on the map plane and elevations determined by measurements of heights above the map plane, or the map plane can be given a scaled vertical movement. Placed in one particular position cutting the model, the outline of the section cut is of equal elevation—a contour. The model can be seen as a result of several methods of projection; for example, projection in complimentary colors or with oscillating images.

c. Combination.—The combination of the two above principles begins with the double projection of the two perspective units but, instead of allowing the projected rays to intersect to form real images, intercepts the projection for true stereoscopic restitution. With apparatus of this classification, the eyes are placed figuratively at the lens positions to view the positive pictures or their perspective equivalents under the same perspective conditions as at exposure. The reduced model of the terrain will then be true to scale in all three dimensions—true stereoscopic restitution as compared with the distorted reconstruction obtained by the simple stereoscope.

81. Measurement of stereoscopic parallax.—*a.* It was demonstrated in paragraph 35*e* that a difference in the angle of parallax implies a difference in stereoscopic depth. Figure 161 shows the profile of a landscape taken on the principal plane of two photographs. (The principal plane is the plane containing the two plumb lines and therefore the stereoscopic base.) The point A is any ground point that appears on both photographs. This point appears on negatives I and II at points a_1 and a_2, respectively, and on the equivalent positives at positions a and a'.

In the figure, line S_1a'' is drawn parallel to line S_2a', making triangle S_1AS_2 similar to triangle $a''S_1a$. From which

$$p/f = B/(H-h) \qquad (1)$$

$$p = \frac{fB}{(H-h)} \qquad (2)$$

where H is the altitude of the camera above sea level, h is the elevation of the point A above sea level and B is the air base, i. e., the distance the airplane moved between exposures. Distance p is the absolute parallax of point A. The parallax of any other point may be similarly

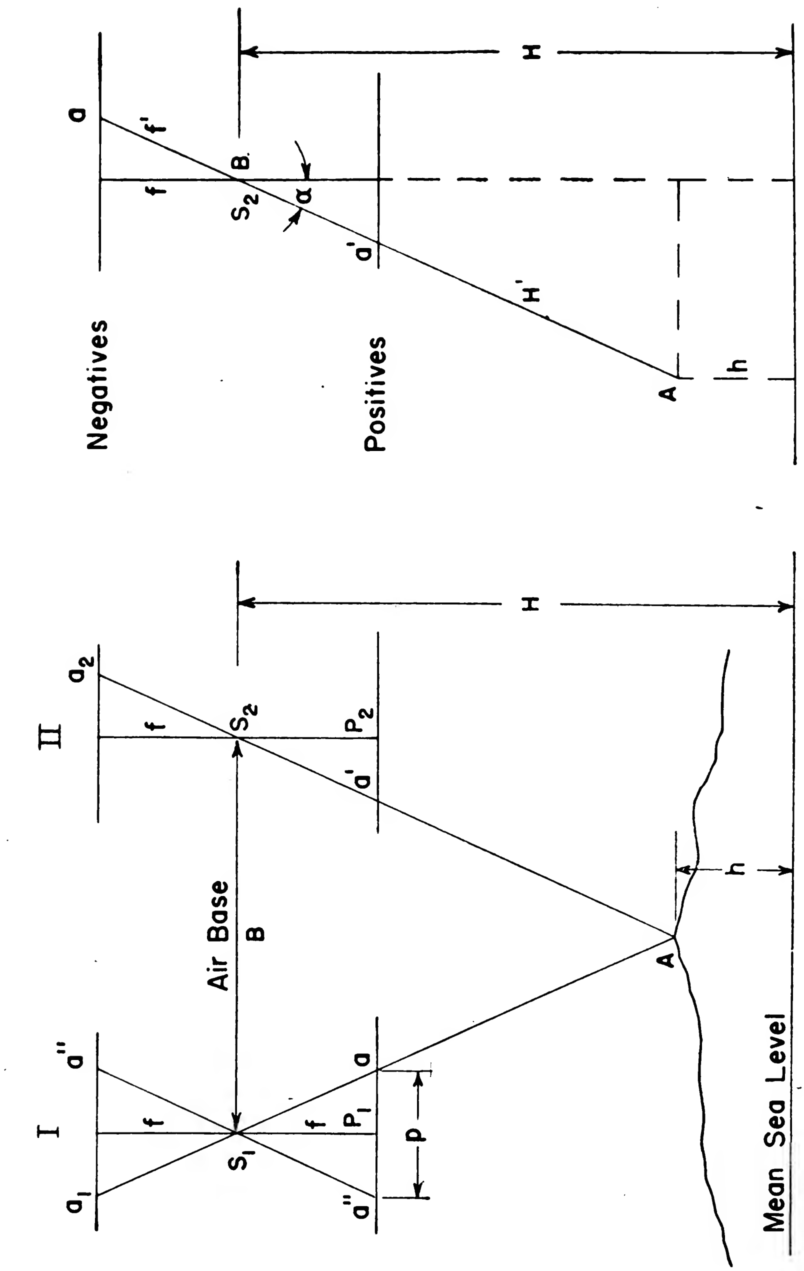


FIGURE 161.—Parallax difference.

determined. The parallax difference of two points depends upon, and is a measure of, the difference between their elevations. The rate of change of the parallax in equation (2) with respect to changes in h may be expressed as

$$dp/dh = \frac{fB}{(H-h)^2} \tag{3}$$

$$dp = \frac{fB(dh)}{(H-h)^2} \tag{3a}$$

or the parallax equation

$$dh/dp = \frac{(H-h)^2}{fB} \tag{3b}$$

To obtain the parallax in terms of the measured stereoscopic base of the photographs, let B_m be the measured stereoscopic base of the photograph, which is equal to the air base multiplied by the mean scale of photograph $f/(H-h)$.

Or

$$B = B_m \frac{(H-h)}{f} \tag{4}$$

By substitution of (4) in equation (3)

$$\frac{dp}{dh} = \frac{fB_m \frac{(H-h)}{f}}{(H-h)^2} = \frac{B_m}{H-h}$$

or

$$dp = \frac{B_m\ dh}{H-h} \tag{5}$$

For small values of change in h compared with H, as, for example, the vertical distance between two contours as compared with the flight altitude

$$\Delta p = \frac{B_m \Delta h}{H-h} \tag{6}$$

Equation (6) expresses the value of the change in parallax (in millimeters if B_m is in millimeters) for a corresponding small change in elevation in feet between two points or two contours on the photograph. In equation (6) it is to be noted that for small changes in elevation the corresponding parallax difference is independent of the focal length of the camera, the over-all size of the photographs, and the percentage of overlap. Examination of equation (1) and figure 161 ① shows that while this equation is built around a profile taken vertically through the camera stations and the plumb points, it is equally applicable to the entire photograph if the parallax is measured parallel to the

stereoscopic base. For example, in figure 161 ②, let it be assumed that point A is a distance H' sin a to the right (or to the left) of the principal plane of the photographs, i. e., containing the stereoscopic base.

Then $p/B = \frac{f' \cos a}{H' \cos a} = \frac{f}{(H-h)}$ as before.

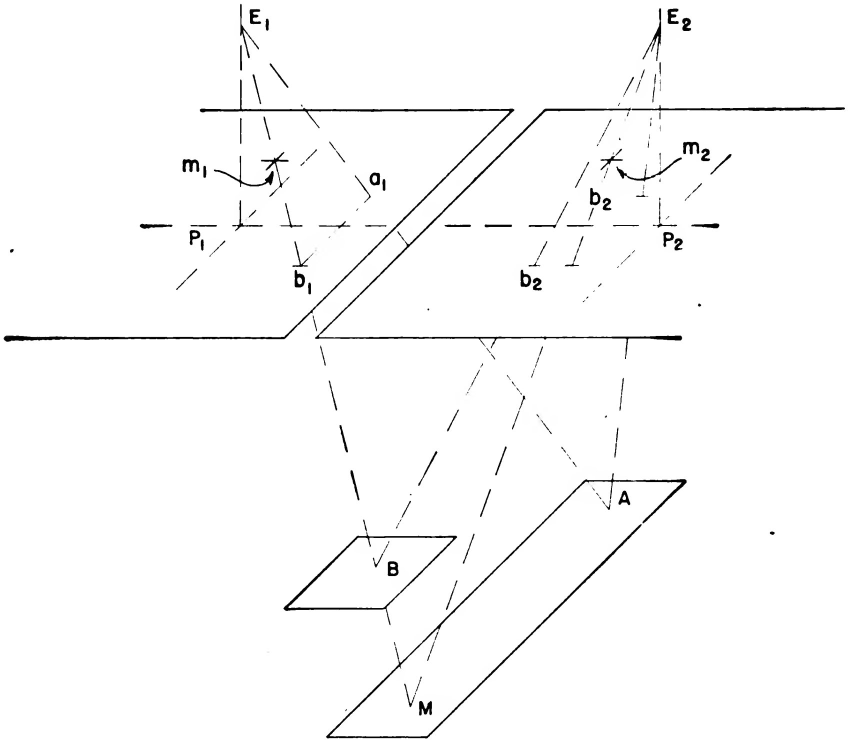


FIGURE 162.—Measurement of parallax.

b. Practical stereoscopic measurement of parallax is based upon the principle of the floating mark. Figure 162 illustrates stereoscopic depth perception, m_1 and m_2 represent the floating mark—two identical simple marks, such as +, Δ, V, ○, or other suitable figures, introduced into the optical system between the eyes and the pictures. These marks, m_1 and m_2, when fused stereoscopically, will give the impression of a single mark M, definitely located in space by the known distance separating m_1 and m_2. If the separation of the marks m_1 and m_2 can be varied, it is evident that the image M can be varied in depth at will, to float in space relative to the landscape, to recede from or to approach and touch the ground, by varying the difference of parallax

existing between the half-images of the mark and those of the point on the ground under immediate observation. When the mark touches the ground at any point, such as B, its parallax has been made to equal that of the ground point. If the distance separating the marks m_1 and m_2 can be read on a suitable scale, this scale can be calibrated by observation on two points of known elevation. The elevation of any ground point can then be determined by interpolation on the scale when the mark is made to touch the ground. The eyes have little or no means of appreciating variation in absolute depth, while the variation in relative depth between the landscape and the mark is readily appreciated. Anyone with normal eyesight can operate a floating mark and measure stereoscopic parallax by the above method with a little practice. The observer concentrates his attention on the ground by a conscious effort of will. The marks seem to take care of themselves, with the floating characteristics described, incidentally to the general view of the ground being studied. Stereoscopic acuity, or the smallest difference in convergence which can be appreciated by an observer, can be measured by special equipment. This ability improves with experience.

c. Serious errors will result in the determination of elevations by parallax measurements on photographs tilted as little as 1° or 2°. Any stereoscopic measurement of parallax with equipment of this class for the determination of elevations must be preceded by correction for tilt as explained in paragraph 88.

82. Stereo-comparagraph.—*a. General.*—(1) The stereo-comparagraph (fig. 163) consists essentially of a stereoscope, a measuring system, a drawing attachment, and an alinement mechanism (not integral with the instrument). In addition, it is provided with a double illuminating fixture to permit the instrument to be used independently of external lighting conditions, a carrying case, and various other accessories. In its application the stereo-comparagraph makes use of the parallax principle for the determination of elevations of objects by means of stereoscopic observation of overlapped vertical aerial photographs or oblique photographs restituted to the vertical.

(2) The lighting fixture fits over two pins on the mirror bracket and is readily detachable from the instrument. It is normally supplied with two 110-volt, 7-watt lamps, each provided with an adjustable reflector and a snap switch. (Lamps of other voltage or wattage can be used if desired.) These lamps are the size used for decorating purposes on Christmas trees.

(3) The carrying case provided for the instrument is designed to house the instrument and all accessories (except the drafting machine

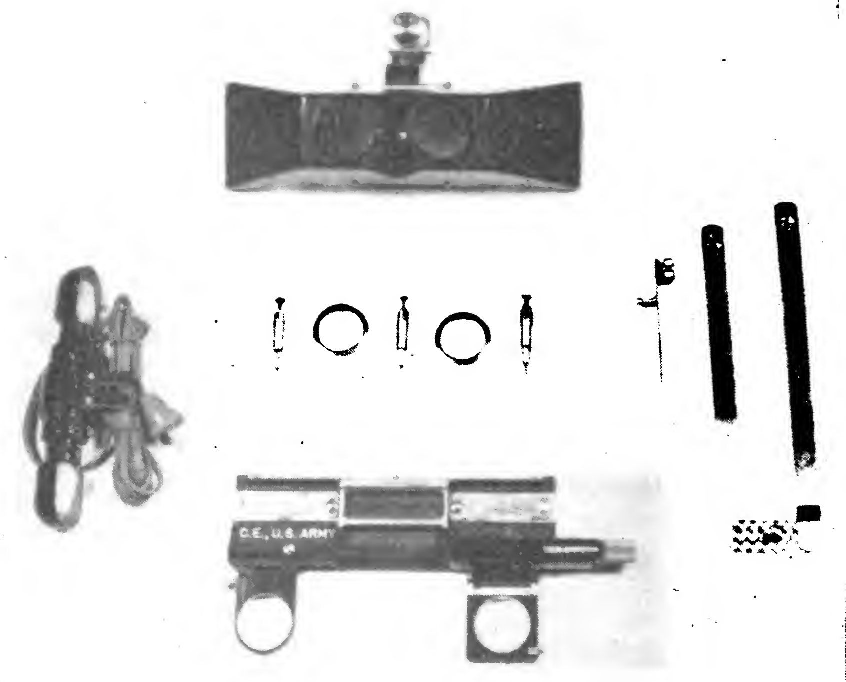


FIGURE 163.—Stereo-comparagraph disassembled.

used for alinement which has its own case), and, in addition, has space provided for photographs, parallax tables, etc.

b. Stereoscope.—(1) The stereoscope (fig. 164) is of the reflecting type, with a pair of matched lenses for magnification of the detail of the photographs. The mirrors are provided with an interpupillary adjustment to allow easy fusion of the images of the photographs and floating marks. This adjustment consists of a knurled screw, located beneath the hood, which changes the angles of the small mirrors when rotated to the right or left.

(2) Figure 165 illustrates the optics of the stereoscope. Two objects are to be attained with this arrangement: the stereoscopic observation of the photographs under examination; and the stereoscopic fusion of two measuring marks, M_1 and M_2 in figure 165, normally located about 16 centimeters apart at positions A_1 and A_2, into the effect of a single floating mark at point A_3.

(3) The stereoscope assembly is easily removed from the base of the instrument by loosening the clamp nut (fig. 163) and sliding the assembly to the right or left until the guide block is clear of the guiding

groove in the base. When replacing the stereoscope, it should be returned approximately to the center of the instrument and clamped firmly in place.

c. Measuring system.—(1) The measuring system of the stereo-comparagraph consists of two marks, M_1 and M_2 in figure 165, in the centers of two lenses (fig. 163) whose separation may be varied, such variation being transferred mechanically and measured by a micrometer. Each floating mark glass is mounted in a retaining ring easily removable from the holder.

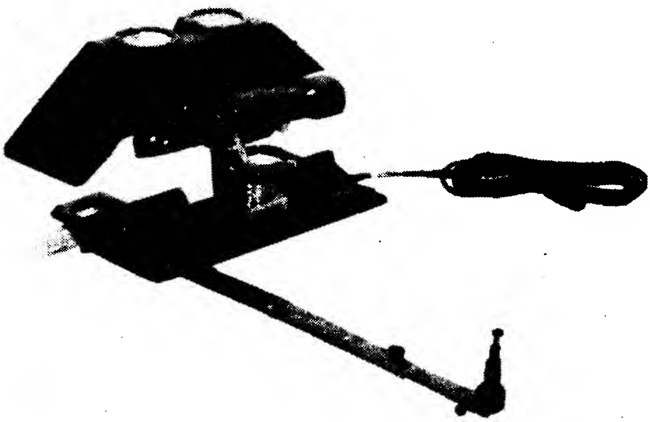


FIGURE 164.—Stereo-comparagraph assembled.

(2) To remove the glass from the left-hand mark, loosen the knurled clamping screw (fig. 163) and push down on the retaining ring. To remove the glass from the right-hand mark, loosen the small set screw in the front of the holder and push down on the retaining ring as before. When replacing them, they should be pressed in all the way until the shoulder on the retaining ring is against the bottom of the holder. The retaining ring should not be pressed on the glass.

(3) The micrometer is graduated from 0 to 25 millimeters, reading directly to hundredths of a millimeter, and is provided with a lock (fig. 163) to clamp it at any setting.

NOTE.—The micrometer head travels ½ milimeter at each revolution. It is graduated to 50 divisions, each division thus indicating 1/100th millimeter. The short marks above the line on the barrel indicate ½ millimeters, and the long marks below the line indicate whole millimeters. The zero of the micrometer

scale of the earlier stereo-comparagraphs was on the left end, while the scale of later models increases from right to left. No change of principle is involved. The micrometer is so placed that it may be read while viewing the photographs through the stereoscope and may also be read directly. The micrometer screw serves both to effect the movement of the right-hand mark and to indicate the extent (in millimeters) of the movement of the floating mark formed by the fusion of the two marks. The right-hand mark assembly is held against the micrometer head by means of a spring so there is no backlash in the movement. It may be moved through a distance of 25 millimeters (the range of the micrometer). The left-hand mark assembly may also be moved a distance of 25 millimeters, in steps of 5 millimeters, by removing the locating pin, figure 2, and sliding the mark assembly to the right or left, replacing the pin to insure exact location of the mark. *If the left-hand mark is moved in this manner during the course of operation, the extent of the movement must be added to (or subtracted from) the micrometer readings made after the movement.*

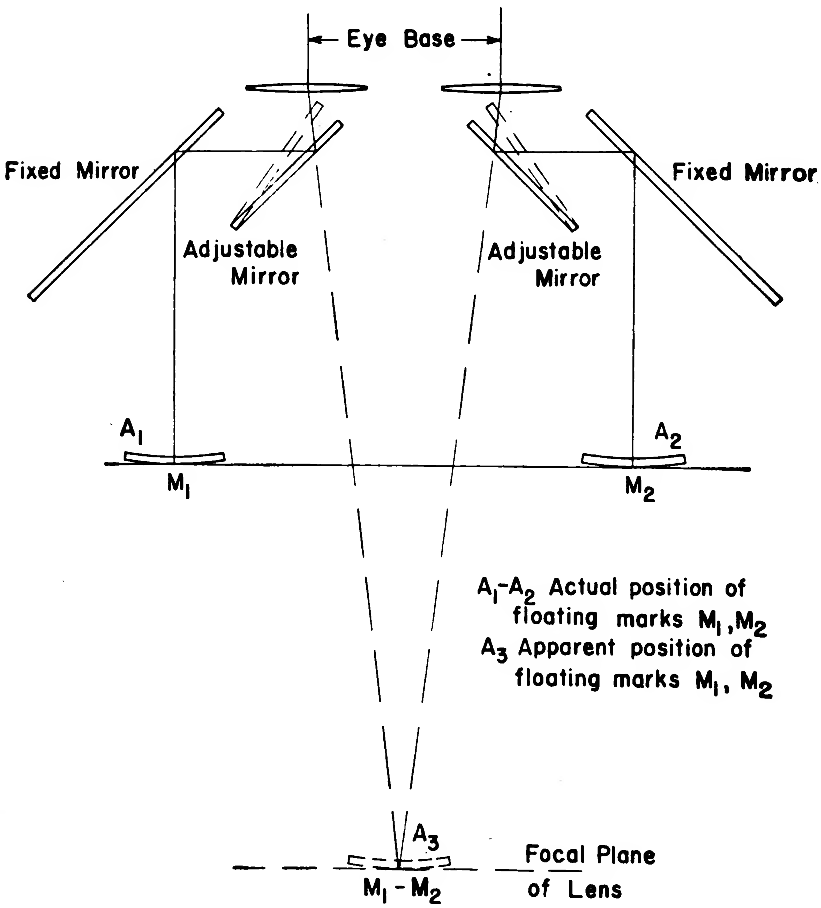


FIGURE 165.—Optical system of stereo-comparagraph.

(4) In addition to the lateral movement, the right-hand mark may also be moved in or out a distance of 1/4 inch on either side of the central location, by means of the small knurled nut *N*, figure 163. The purpose of this movement (known as the "by" motion) is to compensate for tilt, as will be explained later. The left-hand guide rod of the right-hand mark assembly has three small lines engraved on it at the rear 1/4 inch apart. When the rear of the lens holder is on the middle line, a line through the two index marks is parallel to the direction of lateral movement of the marks. This is the position they would occupy if the photographs were free from tip and tilt and were of the same scale. Both mark assemblies may be raised, if desired, to allow inspection of the photograph beneath.

(5) A millimeter scale graduated in 1/2 millimeter divisions is attached to the beveled edge at the rear of the base (fig. 164). The edge of this scale next to the photographs is exactly parallel to the direction of movement of the floating marks and may be used in the measurement of the stereoscopic base of the photographs.

d. Drawing attachment.—(1) The drawing attachment consists of a special pencil mounted at the end of a drawing arm rigidly connected to the base of the instrument (fig. 163) in the same manner that a straightedge is attached to a drafting machine, i. e., a dovetailed slide on the arm slides over a dovetail block on the base. When attaching the arm to the instrument it should be pushed on until it locks securely in place. By this means the stereo-comparagraph draws to a true perspective projection of the left-hand photograph. Form lines so drawn are true to the scale of that photograph. The pencil chuck is located on a short arm which is attached to the main arm by means of the knurled screw shown in figure 163. The two holes in the pencil arm fit over the two locating pins on the main arm. The pencil arm is provided with a ball-pointed rest to hold it at the correct height above the paper, and the arm should always be assembled with this rest down as shown in figure 164. An extension, increasing the length of the arm from 12 to 18 inches, is provided to fit between the main arm and pencil arm if desired, to allow greater freedom in placing the drawing medium with respect to the photographs, and to permit the utilization of large prints. When used, it should be assembled with the two pins up.

(2) The special pencils provided with the instrument fit in the chuck on the pencil arm and are clamped at the desired height by means of the knurled nut of this chuck (fig. 163). They are so constructed that they may be inserted in the chuck with the lead pressure against the paper adjustable to any desired degree. For scanning of the

photographs without drawing, the knurled knob may be raised to the top of the holder and held there by turning the knob until the guide screw rests on the edge of the shell. From the raised position, points may be pricked by pressing down on the stem of the holder. A built-in spring returns it to the upper position. If the pencil does not draw a sufficiently heavy line, additional pressure may be obtained by placing a weight on the arm next to the pencil. Three pencils are normally supplied with the stereo-comparagraph, two for leads of different hardness or colors, and one for the pricker for marking control points.

NOTE.—It is important that the leads used in the pencil be sharpened to a concentric point, otherwise if they are sharpened or changed in the course of the drawing, the lines drawn after the change would be displaced from those already drawn by the amount of the difference in centering. The No. 520 lead repointer is a small hand sharpener which makes a satisfactory point.

e. Alinement mechanism.—The stereo-comparagraph is adapted to the attachment of a standard type drafting machine (par. 8), or any other suitable parallel motion mechanism, to insure the maintenance of the adjustment of the instrument once it is established. To attach the instrument to a drafting machine, it is only necessary to insert the dovetail block on the left of the base in the dovetailed slot of the drafting machine exactly the same as a straightedge would be attached to the machine.

f. Unit equipment.—(1) The unit equipment for a stereo-comparagraph operator includes substantially the following:

Item	Unit	*Quantity*
Parallel motion device, with case	each	1
Stereo-comparagraph (1 each), with case containing the following accessories (or equivalent quality):		
Curve, irregular, xylonite, K&E No. 1860–29, or equal	each	1
Drop spring bow pen, jackknife spring blade, 4-inch	do	1
Pen, drawing, knife spring blade, 4¼-inch	do	1
Pricker	do	1
Shield, erasing	do	1
Triangle, xylonite, 30 by 60°, 8-inch	do	1
Holder, pen, lettering	do	1
Lead repointer, No. 520 or equal	do	1
Pen, lettering, crow-quill or Easterbrook No. 61	do	12
Ink:		
India, ¾-ounce bottle	do	1
Drawing, blue, ¾-ounce bottle	do	1
Drawing, brown, ¾-ounce bottle	do	1
Carmine, drawing, ¾-ounce bottle	do	1

Stereo-comparagraph—Continued

		Quantity
Pencil, drawing:		
HB	each	2
5H	do	2
Eraser:		
Art gum	do	1
Ruby	do	1
Tape, Scotch decorator's, ¾-inch by 10 yds	roll	1
Pad, pencil, pointing	each	1
Paper:		
Lens, cleaning	package	1
Plane table, 8 by 10 inches	sheets	50
Table, parallax (and instruction manual)	each	1
Box leads, pencil:		
3H	do	1
5H	do	1
H	do	1

(2) If operation is for an extended period at a considerable distance from the source of supply, the following replacement parts should be provided in advance:

		Quantity
Lamps, electric, 110-volt, 7-watt, frosted (extra)	each	4
Lenses, index mark (extra)	set	1
Extra pencils and ink as required.		

(3) So supplied the instrument is capable of constant operation for about 6 to 9 months.

83. Application of double projection to topographic mapping.—The principle of double projection has produced widespread invention in the development of intersectional or plane-table photogrammetry. This method of restitution is directly applicable to the military survey problem of mapping in inaccessible areas. In the case of ground photography, overlapping photographs can be exposed from stable ground stations. The length and bearing of the base, the elevations of the camera stations, and the orientation and tilt of the camera can all be determined instrumentally. These data can then be used for the setting of plotting apparatus. As these constants cannot be so determined in the case of aerial strip photography, the reproduction of exposure conditions, location in space of the camera station, determination of tilt, and inclination of the air base constitute the major problem of photogrammetry. The restitution of the terrain obtained by double projection offers the most expeditious or accurate method of

reproducing exposure conditions of overlapping aerial photographs or, in other words, of determining and correcting for tilt without rectification of the individual photographs. The principle of double projection enables the photogrammetrist to use the following apparatus:

a. Direct plotting apparatus from the optical view of the restitution effected by double projection. (See multiplex aero-projector, par. 84.)

b. Automatic plotting apparatus, giving complete application of aerial photography, resulting from the interception of the reprojected rays by a stereo-comparator type of instrument with mechanical translation of orthographic data to a plotting board. (See aero-cartograph and stereo-planigraph, par. 85.)

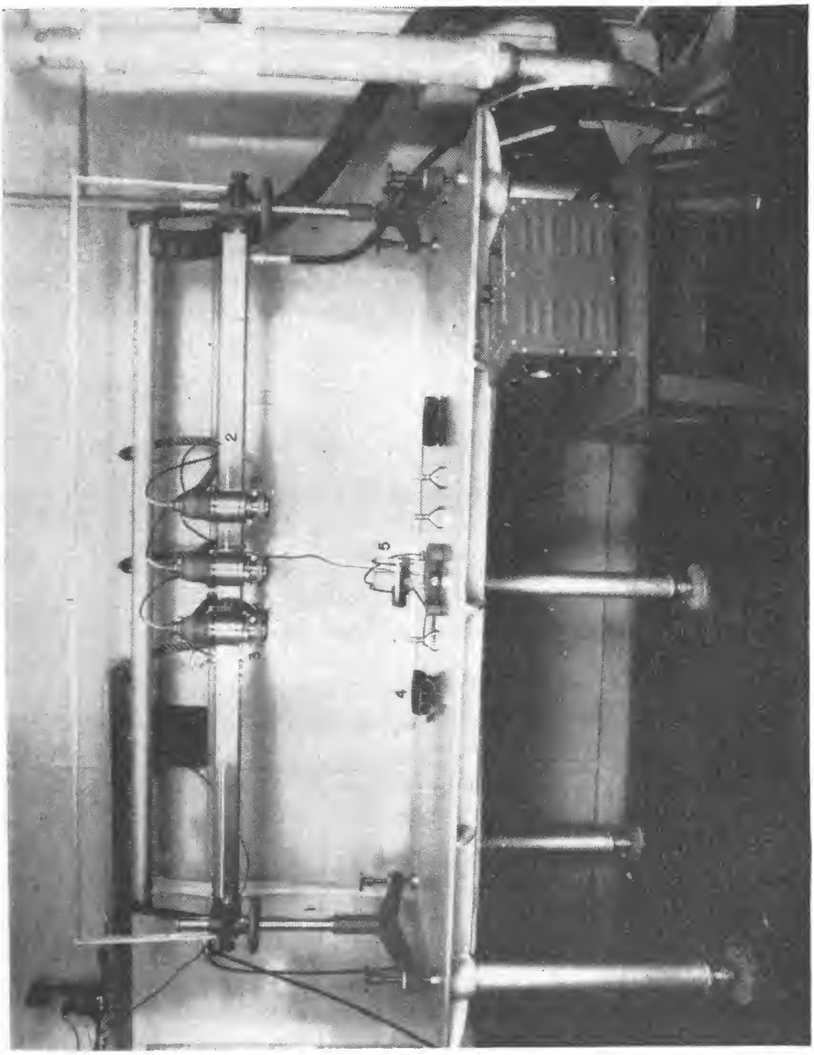
c. Aerotriangulation (control) apparatus, by similar combination of double projection and stereo-photogrammetric principles, without plotting apparatus, for the accurate determination of tilt and rigid orientation of successive photographs in connection with stereoscopic contouring and radial line compilation.

84. Multiplex aero-projector.—*a. General.*—Complete information on this equipment is contained in the manual, "Instructions for the Operation of the Multiplex Aero-Projector," available through the office of the Chief of Engineers. Figure 166 is a front view of the assembled multiplex with three vertical projectors. The table, not furnished as part of the equipment, should be sufficiently solid to support the apparatus and permit operation without vibration or distortion of the top, which should be flat within 0.1 millimeter. The multiplex (fig. 166) consists of adjustable supporting columns (1), a frame (2), containing a scale, a rack, and electric wiring, and projectors (3). The projector barrel contains an electric lamp, condenser lenses, and a slot for the insertion of a color filter for dichromatic projection. The projector body is a small scale reproduction of the aerial camera. The body consists of a cone, lens, and a focal plane frame for the reduced diapositive of the aerial photograph which is to be projected. By means of attached adjusting screws and pinions, each projector body may be given six separate adjustments (fig. 167). The movements are in the direction of the x, y, and z axes and for tilt, tip, and swing.

b. Method of projection.—Overlapping pairs of diapositives are placed in adjacent projectors along the frame and red and green filters are inserted into alternate projectors. After adjustment, a spacial model (fig. 168) is formed above the table. When viewed through glasses (4) (fig. 166), one red and the other green, a clear stereoscopic

model may be seen. The projection from only two projectors may be properly viewed at any one time.

c. *Method of measuring elevation differences.*—The floating mark is a single point of light which is physically raised and lowered within



1, Supporting columns; 2, bar; 3, projectors; 4, filter spectacles; 5, tracing stand.

FIGURE 166.—Multiplex aero-projector.

the spacial model. The mark is the center of an opaque disk on the drawing stand (5) (fig. 166). By turning an adjusting screw, the floating mark may be caused to rise above the spacial model, to make contact with it, or to sink below it.

d. Reducing printer.—Due to their large size, glass contact prints of the original negatives cannot be utilized in the projectors. Reduced diapositives are made on lantern slide plates by a reducing printer. The bottom of the printer contains an electric lamp, a multiple-lens condenser, and glass plates for holding the film flat. The top is fitted with a lens, an optical wedge for regulating the printing, and spring clips for holding the sensitive plate in position.

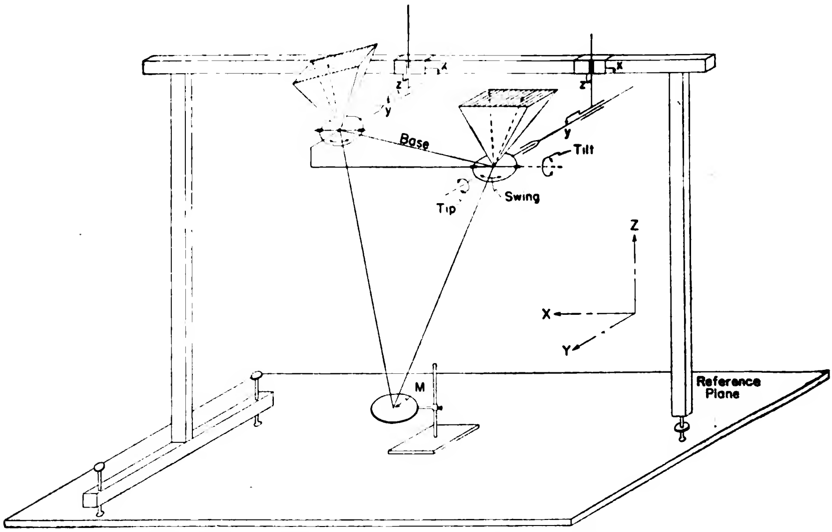


FIGURE 167.—Analytical diagram of multiplex aero-projector.

85. Comparison of instruments.—*a. Double projection photo-mechanical types.*—Taking advantage of the principle of double projection for the reproduction of exposure conditions, important developments have been made with that class of equipment in which the reprojected rays are intercepted by a stereo-comparator type of instrument with or without mechanical translation to effect orthographic projection on a plotting board. As compared with the direct plotting apparatus, it may be stated briefly that a higher precision has been obtained but at the expense of time required in operation. Both the Hugershoff aerocartograph (fig. 169) and the Zeiss stereoplanigraph have been tested and used in this country. One aerocartograph was purchased by the Corps of Engineers. For a detailed description of the construction and operation of the aerocartograph, see the special compilation on the subject by the U. S. Geological Survey, Washington, D. C. The possibilities of equipment of this class for relative independence of ground control are dependent upon three

factors: the skill of the operator in acuity of perception; the accuracy with which the photographs can be set in correspondence; and the accuracy with which parallax can be measured. Both the aerocartograph and the stereoplanigraph are rated with an accuracy of parallactic measurements to the nearest 0.01 mm. However, the later models of the stereoplanigraph surpass the aerocartograph in optical quality, in speed and ease of operation, and in accuracy of results. While no results are at hand for cantilever extension at the usual American photographic scales of 1:20,000 and 1:40,000 from cameras of the 6- to $8\frac{1}{4}$-inch focal length, it may be worth while to estimate comparative figures deduced from work at larger scales. It is believed that the aerocartograph might be rated as accurate in position within 1:500, and suitable for contour intervals within 1/600 of the flight altitude. In the same way, the stereoplanigraph would probably give a position accuracy of 1:1,000 and a contour interval accuracy of 1:1,200.

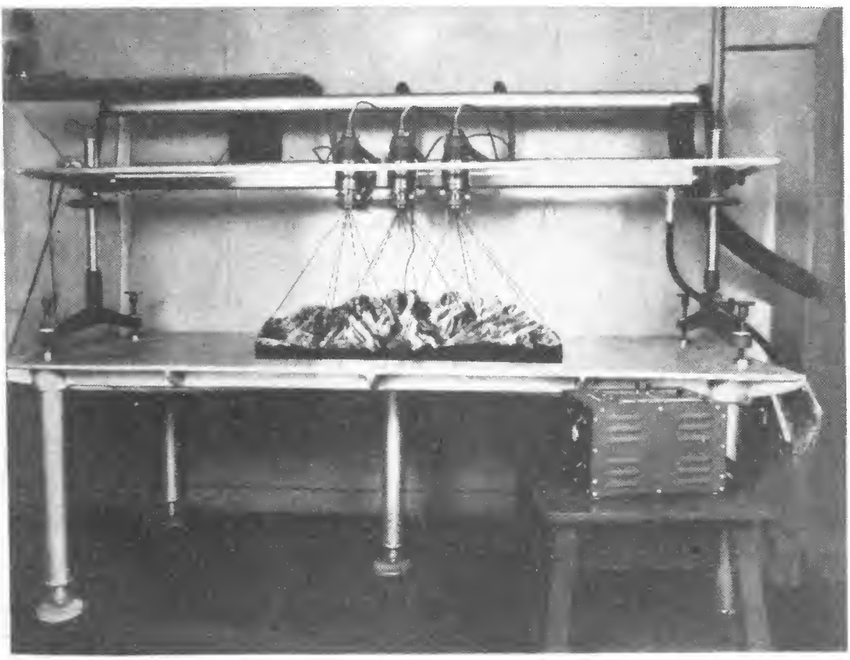


FIGURE 168.—Schematic diagram of multiplex aero-projector in operation.

b. *Multiplex aero-projector.*—This instrument is at some disadvantage in that the scale of the diapositive is less than one-third the negative scale, and the images at the optimum projection distance are about eight times the diapositive scale, making a net enlargement from the

negative to the spacial model of about 2.4 times. The detail lacks the critical sharpness of definition so noticeable in the compound instruments of *a* above. This quality of sharpness is of great aid in the measurement of elevation and in effecting aerotriangulation by the orientation of successive photographs by coincidence of detail. The horizontal scale is usually within 1/500 of the true value. Though vertical accuracies on selected points of good stereoscopic quality approximate 1/600 of the flight altitude, the accuracy when tracing contours is usually about half that made when pointing on definite objects, or possibly 1/350 of the flight altitude.

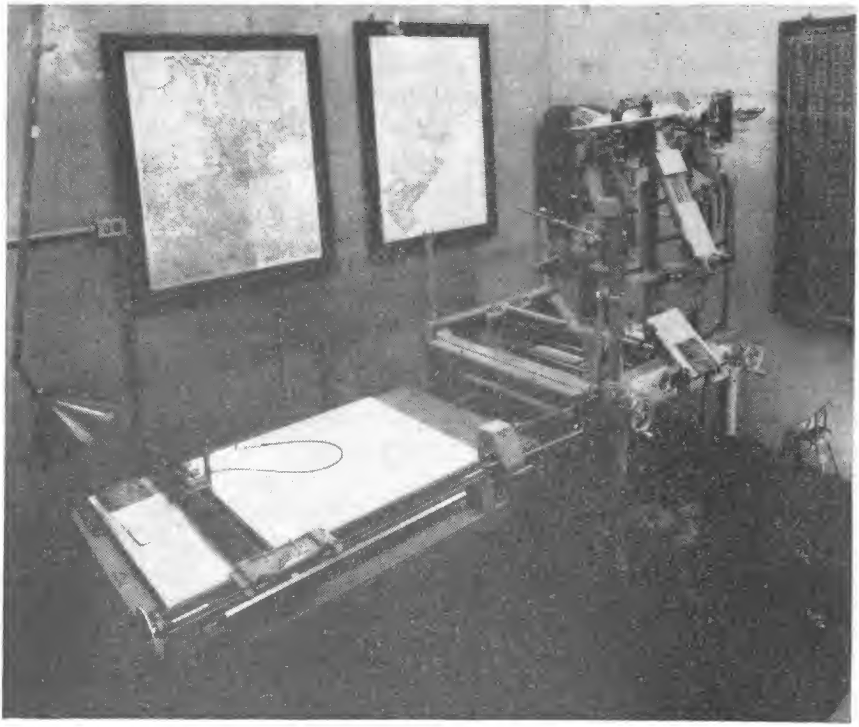


FIGURE 169.—Hugershoff aerocartograph with coordinatograph drafting machine.

c. Stereo-comparagraph.—The stereo-comparagraph permits of a contour interval about 1/250 of the flight altitude. The drafting accuracy of the radial line plot is usually about 1:300, while that of the slotted templet method may be taken as 1:500, provided the detail is not too hastily compiled.

d. Comparative summary.—Remembering that the figures for the aerocartograph and stereo-planigraph are not the results of direct tests

but have been deduced from the work of others, the relative ratings for extension into inaccessible territory may be restated as follows:

Name of instrument	Horizontal accuracy (error from true scale)	Ratio of contour interval to flight altitude	Remarks
Stereo-planigraph	1:1,000	1/1,200	Both require operators of extremely high skill; both are bulky and of delicate construction.
Aero-cartograph	1:500	1/600	
Multiplex aero-projector	1:500	1/350	Best for military use if shelter and space are available. The work can be divided according to skill of personnel.
Stereo-comparagraph with slotted templets.	1:500	1/250	Dependent upon other sources for numerous spot elevations. Probably quickest for small areas, as all available men and equipment can be put to work on receipt of photographs and spot elevations.

Section XVIII

PLANIMETRIC DETAIL AND CONTOURS FROM PHOTOGRAPHS

86. General.—*a.* The tracing of detail is simplified by drafting the compilation sheet at the mean scale of the photographs (par. 87), provided that none of the prints differs from the compilation scale by as much as 5 percent. This method should be used, if possible, as the compilation can be accomplished more rapidly and with better effect. As a rule, the finished compilation can be reduced to the scale of reproduction by photography, which improves the appearance of the drafting and reduces errors of plotting.

b. Photographs of a scale smaller than that of the map might well be enlarged before compilation, if means are available. Any method of enlarging the compilation itself coarsens the drafting and lettering and may introduce unnecessary errors.

c. If there is a lack of photographic equipment, the pantograph should be employed in preparing a map at a scale materially different from that of the photographs. It is possible to pantograph directly from the photograph to the compilation sheet, but the necessary adjustments to the control points are troublesome and accuracy is

diminished. A better map would result from compiling at the scale of the photographs, and then photographing the complete detail to a new projection at the map scale.

87. Tracing detail from photographs.—*a. Method.*—(1) The detail should be traced from the photographs marked for the construction of the control sheet, as the adjusted control points show the exact map position of the points marked. The general procedure is to place the compilation sheet over the marked photograph in proper relation to the adjusted control and to trace desired data from the photograph. If the photographs are 1:30,000 or smaller, the detail should be interpreted under a magnifying stereoscope and emphasized where necessary with crayon or pencil of an appropriate color before being traced. If the scales are in agreement and the tilt and relief distortions are very small, the control points may fit exactly, and any or all of the detail may be traced from the central portion of such print without adjustment. Usually the points do not fit, and only the detail in the immediate vicinity of a single point can be traced while that point is in coincidence with the corresponding point of the photograph. During all of the tracing, the ray toward the principal point from the portion being traced must be kept in coincidence with the corresponding ray of the photograph, as all relief and tilt distortions are radial from the principal points. If sufficient auxiliary control points have been provided, all adjustments will be quite small, and frequently all three points of a 2-inch triangle will fit and the area can be traced without adjustment. If the fit is missed by only a few hundreths of an inch, the detail can be traced about halfway from one point and the remainder traced after bringing the other point into position. If the difference is as much as .05 inch, one-third could be traced in the first position, and the middle third while both points are an equal amount off. No appreciable error will arise from making these small adjustments by eye, so long as the sheet and the photograph are kept mutually oriented. As the errors increase more rapidly toward the edges, only the central portion, about halfway to the centers of adjacent photographs, should be traced. In this manner, working from one triangle of photographic control points to the next, the best area of each print is traced. Particular attention will have to be given to the areas along the course lines if the terrain is rough. In this case the detail will have to be adjusted in proportion to the distances from the principal points.

(2) Some draftsmen prefer to complete all detail as the work progresses. Probably most prefer to trace shore line, roads, and prominent features, first, with great attention to position. One very satisfactory

method of compiling is to trace, first, the through highways, canals, railways, etc., thus dividing the sheet into controlled areas, then subdividing these areas with secondary roads, field lines, etc. When any difficulty is encountered in reconciling features with radial lines, a check the draftsman must constantly apply, additional points must be located by radial intersection. In areas of much relief control points must be very close together, perhaps within ½ inch of each other. The number required may be reduced somewhat by making auxiliary intersections at critical points with uniform slopes in between. Over such terrain, the data along the ridges should be adjusted together and data in the valleys together. If the road corners have been or can be located on the tracing by intersection, the construction of the road net is quite simple. Once the main and secondary road nets are traced, they provide a supplementary control for the remaining details which may be traced more rapidly and with greater attention to drafting and to the selection of the more important details. Special attention should be given to features of tactical importance.

(3) If the photographs have been contoured stereoscopically or otherwise, contours are traced as horizontal detail; in other words, adjusted on minor control points in exactly the same manner as horizontal detail. Slight adjustments will sometimes be required at the junctions where the details of two adjoining photographs come together. The work should be done systematically to avoid omissions, repetitions, and confusion. If the areas of the overlaps have been so divided as to contour entire topographical features on a single photograph (par. 38*d*), both planimetry and topography should be traced in the same manner. If the border contour ends have not been transferred as there suggested, considerable adjustment may be necessary. This may be performed on the compilation sheet or may be accomplished by a draftsman other than the compiler as a separate stage. In that event rather rough pencil tracings of the adjoining borders will be useful. These are matched and the adjustments made in colored pencil and transferred to the photographs in the same color, leaving the original contours intact, in case any question should arise. This procedure will speed and improve the work of compilation. The contours from the stereo-comparagraph are compiled separately from the planimetry (par. 88*h*).

(4) The drafting and inking depend upon how the compilation is to be utilized. If the reproduction is to be in colors, the tracing might be left in black pencil and several blue-line copies made from a negative on metal-mounted sheets, sensitized for blue printing, or by lithography. A separate copy to a common scale is made for each color by inking in

black only the lines which are to be reproduced in that color. The same method will do for blue-line field sheets, except that all the lines are inked in their appropriate colors on the completion of each day's field work. If the compilation is to be reproduced in a single color, at the natural scale or after photographic copying to the scale of reproduction, all the lines will have to be inked.

(5) In any case the entire road net should first be penciled with a 2H or 3H pencil, tracing only the center lines. Occasional alterations are more easily made, and blots are avoided. The remainder of the details may be traced in ink. A completed compilation is shown in figure 170. For photographic reproduction, lines can be drawn too fine and too close together. The finest lines should be designated as fine, strong lines. The clear or white space between such lines should not be less than three times the width of the line (road lines, for example). Topographic symbols in crowded areas, such as the hachuring along levees, cuts, and fills, should show even wider clear space between lines. Omit nonessential information in order to show ground control stations, bench marks, etc.; where detail must be shown, omit the symbol for the control point and indicate its position by a leader from one side. Many draftsmen prefer to ink all detail, including roads, with a lithographic crow-quill pen. Others prefer to do most of the inking, including freehand, with a small ruling pen. The idea is to get lines of even quality with plenty of ink on them for good photographic reproduction.

(6) For a single color map, the lettering must be put on the compilation sheet following the principles of paragraph 94*d*. The marginal data may be added as explained in paragraph 48*a* and illustrated in figure 88.

b. Exercise No. 29: tracing detail from photographs.—On the adjusted control sheet prepared in exercise No. 28, trace the detail, similar to that shown in figure 170, from the photographs employed in that exercise. In order to become familiar with the principles of compiling detail from photographs and to avoid defacing the larger compilation sheet, a practice exercise should be executed in advance on a separate piece of film base to which the control points for two or three of the photographs have been traced.

88. Topography with stereo-comparagraph.—*a. Stereoscopic adjustment.*—Before the operation is commenced, the stereo-comparagraph must be adjusted for the interpupillary distance of the individual operator. This adjustment is said to have been made only when the operator is able to fuse the two index marks without eye strain and bring their fused image onto the spacial model of the

photographs. (See par. 35.) This may be accomplished in a variety of ways:

(1) Where the operator has never before used a stereoscope, the following procedure may be employed to advantage:

(*a*) Attach stereo-comparagraph to alinement mechanism (fig. 164) and place it over a sheet of clear, white paper.

(*b*) Punch holes about 1/4 inch in diameter in two paper strips about 4 inches long. Overlap blank ends and hold strips in one hand about 1 inch in front of eyes so that lines of sight from the two eyes pass through the holes, and distant objects may be observed clearly as through field glasses. (Holes made by an ordinary paper punch are of the proper size, or a sheet of ordinary loose-leaf paper may be torn in two and used for this purpose.) When the holes merge into a clear circle, the spacing is correct. This spacing corresponds to the interpupillary distance of the eyes. Fasten the two pieces of paper together with a paper clip or tape so that the spacing of the holes will be maintained.

(*c*) Place two paper strips used for measurement of interpupillary distance over lenses of stereoscope with holes as nearly centered as their spacing will permit. Hold or otherwise secure paper strips to stereoscope.

(*d*) Set stereoscope about middle of slide on base.

(*e*) Set interpupillary adjusting screw and (by) motion in their midpositions.

(*f*) Without moving the paper, close left eye and move left index mark retaining ring along base until mark is in center of field of view and replace pin. Repeat for right eye. This places the index marks for observation without straining the eyes. When the paper is removed and both eyes are opened, the two marks should appear as one, and the retaining rings should be fused into an image as of one ring.

(*g*) Should there be a slight delay in the fusion, when both eyes are open, or the eyes "draw" in order to obtain fusion, the interpupillary adjustment of the mirrors may be changed until fusion is obtained without strain. If this is not accomplished at the first trial the operation should be repeated until it is. A convenient test for the absence of eye strain is lazily to open and close the eyes while looking through the stereoscope. If fusion is readily obtained when the eyes are opened, the adjustment is correct and fatigue will not result. If the retaining rings appear to creep when the eyes are opened, the adjustment should be varied until ready fusion is obtained immediately the eyes are opened.

(*h*) When the adjustment for interpupillary distance has been made, any similar images brought under the index marks will automatically fuse and may be observed stereoscopically.

(2) For persons acquainted with stereoscopic observation of aerial photographs, the interpupillary adjustment may be made by attaching the stereo-comparagraph to the alinement mechanism and placing the instrument over a thin sheet of clean, white paper. Then—

(*a*) Set and lock stereoscope at or near middle of base.

(*b*) Set and pin left retaining ring in its midposition along base.

(*c*) Set (by) motion in its zero position.

(*d*) Adjust interpupillary setting of stereoscope and micrometer until index marks fuse into a single floating mark without eye strain, with micrometer near its midpoint on scale.

b. Marking photographs.—(1) *Principal points.*—Prick principal points and transfer them to adjacent photographs as described in paragraph 75. Mark them by broken dashes not over 0.2 inch long. This establishes the direction of flight and the stereoscopic base. Substitute centers will not serve for this purpose.

(2) *Elevation points.*—Prick the exact position of each elevation point and circumscribe it with a fine, blue circle of about 1/4 inch diameter if there is danger of the exact position being lost. The name or other distinguishing mark of each point (if any) and the corresponding elevation should be recorded beside it in neat letters and numerals. If care is taken to avoid covering important detail, these markings will not disturb the operator.

(3) *Photographic control points.*—If the topography is to be adjusted to a uniform scale and joined to the topography of other photographs, all critical points to be used in the radial line adjustment should be pricked on at least the left photograph of the pair. These points should be transferred to the contoured stereo-sketch as hereafter explained.

c. Adjusting photographs.—(1) *Deliberate method.*—This method will be used only in case of a short overlap or when the principal points fall in a lake or on similar detail which makes the transfer of the points difficult or doubtful.

(*a*) Place left print of stereoscopic pair face up in any convenient drawing position on drawing board or table on which instrument is mounted. (If there is reason to believe the set-up will be disturbed prior to the completion of the work, the prints should be placed on a sheet of drawing paper or bristol board in order that both photographs may be taken up together without disturbing their relative orientation. A piece of firm, smooth-surfaced wallboard, like

masonite, is best for this purpose.) Orient left photograph by swinging it until stereoscopic base line is exactly parallel to beveled edge along rear of stereo-comparagraph. When this photograph has been so oriented, it may be fastened to the table by tape along the edges or by rubber cement as may be preferred. If tape is used, small bits at the corners are sufficient until adjustment is complete. Scotch decorator's tape, ¾ inch wide, is most suitable.

(*b*) Place stereo-comparagraph over left photograph so that left floating mark falls on center point of left photograph. Place right photograph of pair under stereo-comparagraph and orient it with respect to left photograph, causing position of center point of left photograph where it appears on right photograph to be directly under right floating mark without disturbing setting of micrometer.

(*c*) Observe through stereoscope and complete stereoscopic adjustment of center point of left photograph, causing fused image of floating marks to fall exactly on image of left center point on surface of stereoscopic model without parallax. (At this stage, parallax is recognized as offset between the images of the points and the floating mark.)

(*d*) While holding the right photograph so as not to disturb the position of the left center point, move stereo-comparagraph until left floating mark falls on center point of right photograph where it appears on left photograph. Swing right photograph until right floating mark falls upon stereoscopic base line, and by means of micrometer bring instrument into stereoscopic adjustment with floating mark resting on center point without parallax.

(*e*) If the image of the principal point of the photographs falls in water or on land where there is no distinguishable feature, and it is impossible to transfer readily the position of the center points, prick centers of each photograph as determined by collimating marks. Place a piece of tracing paper over each photograph and draw rays from pricked point through four sharply defined points in overlap area. When the paper is placed over the other photograph of the pair and these rays are caused to pass through the same points, the position of the center point will have been located. Orientation based upon this manner of location of center points should be checked by stereoscopic adjustments on other points. Make these adjustments on points near the four corners of the stereoscopic model and, if such are available, on at least three points known in elevation. If the photographs are without tip and tilt and are of the same scale, a perfect adjustment will be obtained without resort to the (by) motion, but if there are tip and tilt, the residual vertical parallax may be removed by means of the (by) motion.

(*f*) When the parallax has been removed, i. e., when the adjustment is complete and there is a clear, spacial model throughout the area of overlap, both prints may be securely fastened to the drawing table or mounting sheet. In using rubber cement, it is convenient to coat the mount and the backs of both prints and to secure the left-hand photograph before commencing the adjustment. A piece of film base is kept under the right-hand print until the final position is attained.

(2) *Alternate method.*—An alternate method of stereoscopic adjustment is often used by experienced personnel, since it requires only a fraction of the time required for adjustment by the deliberate method. It gives results which are quite as accurate as those from the deliberate method, except where the transfer of the principal points is doubtful.

(*a*) Mark photographs as previously outlined.

(*b*) Fuse index marks into a single floating mark without eye strain with micrometer near center of its scale.

(*c*) Measure distance between index marks (for the purpose of explanation, let it be assumed that this distance is 6.27 inches).

(*d*) Temporarily fasten left photograph to a sheet of drawing paper or bristol board by means of a pin or pricker through its center point. Place right photograph to right of left photograph so there is about 6¼ inches between pricked center point of left photograph (see pricker, fig. 171) and corresponding position of this point on right photograph (see small pin, fig. 171). Fasten right photograph to drawing paper or bristol board by means of a pricker through its center. Place straightedge against these two prickers and swing both photographs until their stereoscopic base line is parallel to edge of ruler, i. e., until two marked base end points appear at edge of scale (fig. 171). Fasten photographs to mounting sheet with tape around their edges or by rubber cement ((1) (*a*) above).

(*e*) Place stereo-comparagraph over mounted photographs in drawing position and swing them as a whole until stereoscopic base of instrument is parallel to established base of photographs, and secure sheet holding photographs to drawing table. The floating mark can be placed on the stereoscopic model so formed, and if the work has been done carefully, scanning or drawing may commence. Use (by) motion of right index mark to remove residual vertical parallax.

d. Sketching form lines.—In the operation of the stereo-comparagraph, differences in elevation are represented by the differences in parallax measured by the micrometer. Such measurement is obtained by bringing the fused image of the index marks (the floating mark) into contact with the spacial model formed by the stereoscopic observation of the photographs and noting the reading for each point

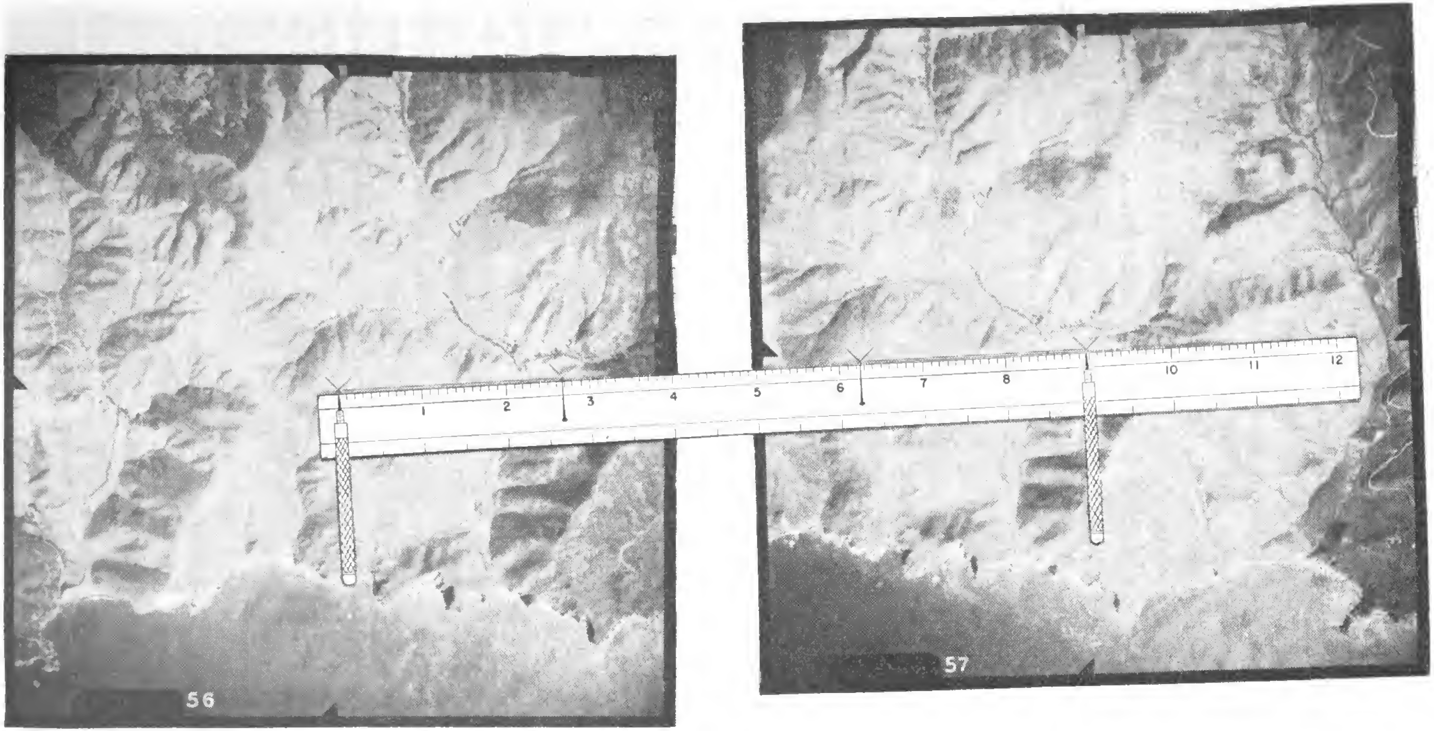


FIGURE 171.—Rapid method of adjusting photographs for stereo-comparagraph.

measured. The difference in feet corresponding to the difference in parallax (indicated by the difference in micrometer readings) may be obtained by computation or from the parallax tables in *e* below. To obtain the feet difference in elevation between any two points, it is necessary to know the elevation of at least one point and refer all other elevations to this point. The elevation of one point is sufficient only when the photographs are free from tip, tilt, and distortion. Attempts should not be made to contour photographs when the elevation of only one point is known. The result would be form lines referred to an indeterminate datum. However, when the approximate scale is known, form lines may be drawn with an error in spacing between the lines of the same order as the approximation of scale. In this case the result has an accuracy of a sketch. When it is desired to obtain form lines, make the best possible determination of $(H-h)$, and enter the parallax tables to obtain the parallax difference corresponding to the desired interval between form lines and use these values for setting the floating mark and for subsequent work. The percentage of errors between adjacent form lines will be (almost) the percentage of error in the determination of $(H-h)$ which in most cases will be within the probable error of observation, but it is cumulative and would introduce considerable absolute errors in country of great relief.

e. Parallax tables.—(1) *Basis of computation.*—Parallax tables may be easily computed for values of Δh equal to 20 feet or any other suitable contour interval, and $B_m=100$ millimeters for changes in flight altitude H from 5,000 feet to 25,000 feet for use with vertical photographs from any aerial camera. Such a table will be found on the pages following. It is necessary in the use of these tables to consider the measured stereoscopic base B_m of the photographs as a percentage of 100, and to multiply the corresponding parallax by this percentage to obtain the parallax corresponding to the change in contour interval for the particular photographs under consideration. This table is a solution of equation (6) (par. 81*a*) for an assumed stereoscopic base of 100 millimeters in increments of 20 feet difference in elevation, for variations in $(H-h)$ from 25,000 feet to 10,000 feet, and in increments of 10 feet from 10,000 feet to 5,000 feet. For the computation of the parallax table, equation (6) has the form

$$p(\text{mm.})=\frac{100(\text{mm.})\times 20\ (\text{ft.})}{(H-h)\ (\text{ft.})}$$

The values of parallax difference are given in millimeters so they can conveniently be used with the stereo-comparagraph whereon the

differences in parallax readings of the photographs are indicated directly in millimeters. If it is required to use the stereo-comparagraph when the flight altitude and the elevations are expressed in meters, a table of parallax values conforming to contour intervals may be similarly computed. Column (3) of the table is the sum of the increments of parallax difference between the limits of $(H-h)=25{,}000$ and $(H-h)=5{,}000$. This column is used to refer the elevations to a sea level datum for the purpose of making corrections for the effect of tip and tilt, as will be explained further on, and for the quick determination of contour intervals greater than the increments shown in the table.

TABLES OF STEREOSCOPIC PARALLAX*

For

$$\Delta p=\frac{B_m\ \Delta h}{H-h}$$

between the limits of $(H-h)=25{,}000$ feet to $(H-h)=10{,}000$ feet, when $B_m=100$ millimeters and $\Delta h=20$ feet, and between the limits of $(H-h)=10{,}000$ feet to $(H-h)=5{,}000$ feet, when $B_m=100$ millimeters and $\Delta h=10$ feet.

$(H-h)$ ft.	Δp mm.	$\Sigma\Delta p$ mm.	$(H-h)$ ft.	Δp mm.	$\Sigma\Delta p$ mm.	$(H-h)$ ft.	Δp mm.	$\Sigma\Delta p$ mm.
25000	0	0	24480	0. 082	2. 102	23960	0. 083	4. 249
24980	0. 080	0. 080	60	0. 082	2. 184	40	0. 084	4. 333
60	0. 080	0. 160	40	0. 082	2. 265	20	0. 084	4. 416
40	0. 080	0. 240	20	0. 082	2. 347	23900	0. 084	4. 500
20	0. 080	0. 321	24400	0. 082	2. 429	23880	0 084	4. 583
24900	0. 080	0. 401	24380	0. 082	2. 511	60	0. 084	4. 667
24880	0. 080	0. 481	60	0. 082	2. 593	40	0. 084	4. 751
60	0. 080	0. 562	40	0. 082	2. 675	20	0. 084	4. 835
40	0. 080	0. 642	20	0. 082	2. 758	23800	0. 084	4. 919
20	0. 081	0. 723	24300	0. 082	2. 840	23780	0. 084	5. 003
24800	0. 081	0. 803	24280	0. 082	2. 922	60	0. 084	5. 087
24780	0. 081	0. 884	60	0. 082	3. 005	40	0. 084	5. 171
60	0. 081	0. 965	40	0. 082	3. 087	20	0. 084	5. 256
40	0. 081	1. 045	20	0. 083	3. 170	23700	0. 084	5. 340
20	0. 081	1. 126	24200	0. 083	3. 252	23680	0. 084	5. 425
24700	0. 081	1. 207	24180	0. 083	3. 335	60	0. 084	5. 509
24680	0. 081	1. 288	60	0. 083	3. 418	40	0. 085	5. 594
60	0. 081	1. 369	40	0. 083	3. 501	20	0. 085	5. 678
40	0. 081	1. 450	20	0. 083	3. 583	23600	0. 085	5. 763
20	0. 081	1. 532	24100	0. 083	3. 666	23580	0. 085	5. 848
24600	0. 081	1. 613	24080	0. 083	3. 749	60	0. 085	5. 933
24580	0. 081	1. 694	60	0. 083	3. 832	40	0. 085	6. 017
60	0. 081	1. 776	40	0. 083	3. 916	20	0. 085	6. 102
40	0. 081	1. 857	20	0. 083	3. 999	23500	0. 085	6. 188
20	0. 082	1. 939	24000	0. 083	4. 082	23480	0. 085	6. 273
24500	0. 082	2. 020	23980	0. 083	4. 166	60	0. 085	6. 358

*Slight discrepancies in the last place between values in columns Δp and $\Sigma\Delta p$, due to three decimal place contraction, will be apparent in some instances; however they do not affect the accuracy of results as micrometer readings on the stereo-comparagraph are to hundredths of millimeters (mm) only.

(H—h) ft.	Δp mm.	ΣΔp mm.	(H—h) ft.	Δp mm.	ΣΔp mm.	(H—h) ft.	Δp mm.	ΣΔp mm.
23440	0. 085	6. 443	22280	0. 090	11. 519	21120	0. 095	16. 865
20	0. 085	6. 529	60	0. 090	11. 608	21100	0. 095	16. 960
23400	0. 085	6. 614	40	0. 090	11. 698	21080	0. 095	17. 055
23380	0. 086	6. 700	20	0. 090	11. 788	60	0. 095	17. 150
60	0. 086	6. 785	22200	0. 090	11. 878	40	0. 095	17. 245
40	0. 086	6. 870	22180	0. 090	11. 968	20	0. 095	17. 340
20	0. 086	6. 956	60	0. 090	12. 059	21000	0. 095	17. 435
23300	0. 086	7. 042	40	0. 090	12. 149	20980	0. 095	17. 531
23280	0. 086	7. 128	20	0. 090	12. 239	60	0. 095	17. 626
60	0. 086	7. 214	22100	0. 090	12. 330	40	0. 095	17. 721
40	0. 086	7. 300	22080	0. 091	12. 420	20	0. 096	17. 817
20	0. 086	7. 386	60	0. 091	12. 511	20900	0. 096	17. 913
23200	0. 086	7. 472	40	0. 091	12. 602	20880	0. 096	18. 008
23180	0. 086	7. 559	20	0. 091	12. 692	60	0. 096	18. 104
60	0. 086	7. 645	22000	0. 091	12. 783	40	0. 096	18. 200
40	0. 086	7. 731	21980	0. 091	12. 874	20	0. 096	18. 296
20	0. 086	7. 818	60	0. 091	12. 965	20800	0. 096	18. 392
23100	0. 087	7. 904	40	0. 091	13. 056	20780	0. 096	18. 488
23080	0. 087	7. 991	20	0. 091	13. 148	60	0. 096	18. 585
60	0. 087	8. 078	21900	0. 091	13. 239	40	0. 096	18. 681
40	0. 087	8. 164	21800	0. 091	13. 330	20	0. 096	18. 778
20	0. 087	8. 251	60	0. 091	13. 422	20700	0. 097	18. 874
23000	0. 087	8. 338	50	0. 092	13. 513	20680	0. 097	18. 971
22980	0. 087	8. 425	20	0. 092	13. 605	60	0. 097	19. 068
60	0. 087	8. 512	21800	0. 092	13. 697	40	0. 097	19. 164
40	0. 087	8. 599	21780	0. 092	13. 788	20	0. 097	19. 261
20	0. 087	8. 687	60	0. 092	13. 880	20600	0. 097	19. 358
22900	0. 087	8. 774	40	0. 092	13. 972	20580	0. 097	19. 456
22880	0. 087	8. 861	20	0. 092	14. 064	60	0. 097	19. 553
60	0. 087	8. 949	21700	0. 092	14. 156	40	0. 097	19. 650
40	0. 088	9. 036	21680	0. 092	14. 249	20	0. 097	19. 747
20	0. 088	9. 124	60	0. 092	14. 341	20500	0. 098	19. 845
22800	0. 088	9. 212	40	0. 092	14. 433	20480	0. 098	19. 943
22780	0. 088	9. 299	20	0. 092	14. 526	60	0. 098	20. 040
60	0. 088	9. 387	21600	0. 993	14. 618	40	0. 098	20. 138
40	0. 088	9. 475	21580	0. 093	14. 711	20	0. 098	20. 236
20	0. 088	9. 563	60	0. 093	14. 804	20400	0. 098	20. 334
22700	0. 088	9. 651	40	0. 093	14. 896	20380	0. 098	20. 432
22680	0. 088	9. 739	20	0. 093	14. 989	60	0. 098	20. 530
60	0. 088	9. 827	21500	0. 093	15. 082	40	0. 098	20. 629
40	0. 088	9. 916	21480	0. 093	15. 175	20	0. 098	20. 727
20	0. 088	10. 004	60	0. 093	15. 268	20300	0. 098	20. 825
22600	0. 088	10. 093	40	0. 093	15. 362	20280	0. 099	20. 924
22580	0. 089	10. 181	20	0. 093	15. 455	60	0. 099	21. 023
60	0. 089	10. 270	21400	0. 093	15. 548	40	0. 099	21. 121
40	0. 089	10. 358	21380	0. 094	15. 642	20	0. 099	21. 220
20	0. 089	10. 447	60	0. 094	15. 736	20200	0. 099	21. 319
22500	0. 089	10. 536	40	0. 094	15. 829	20180	0. 099	21. 418
22480	0. 089	10. 625	20	0. 094	15. 923	60	0. 099	21. 517
60	0. 089	10. 714	21300	0. 094	16. 017	40	0. 099	21. 617
40	0. 089	10. 803	21280	0. 094	16. 111	20	0. 099	21. 716
20	0. 089	10. 892	60	0. 094	16. 205	20100	0. 099	21. 815
22400	0. 089	10. 981	40	0. 094	16. 299	20080	0. 100	21. 915
22380	0. 089	11. 071	20	0. 094	16. 393	60	0. 100	22. 015
60	0. 089	11. 160	21200	0. 094	16. 487	40	0. 100	22. 114
40	0. 089	11. 250	21180	0. 094	16. 582	20	0. 100	22. 214
20	0. 090	11. 339	60	0. 094	16. 676	20000	0. 100	22. 314
22300	0. 090	11. 429	40	0. 095	16. 771	19980	0. 100	22. 414

$(H-h)$ *ft.*	Δp *mm.*	$\Sigma\Delta p$ *mm.*	$(H-h)$ *ft.*	Δp *mm.*	$\Sigma\Delta p$ *mm.*	$(H-h)$ *ft.*	Δp *mm.*	$\Sigma\Delta p$ *mm.*
19960	0. 100	22. 514	18800	0. 106	28. 502	17640	0. 113	34. 871
40	0. 100	22. 615	18780	0. 106	28. 608	20	0. 113	34. 984
20	0. 100	22. 715	60	0. 107	28. 715	17600	0. 114	35. 098
19900	0. 100	22. 815	40	0. 107	28. 821	17580	0. 114	35. 211
19880	0. 101	22. 916	20	0. 107	28. 928	60	0. 114	35. 325
60	0. 101	23. 017	18700	0. 107	29. 035	40	0. 114	35. 439
40	0. 101	23. 117	18680	0. 107	29. 142	20	0. 114	35. 553
20	0. 101	23. 218	60	0. 107	29. 249	17500	0. 114	35. 667
19800	0. 101	23. 319	40	0. 107	29. 356	17480	0. 114	35. 782
19780	0. 101	23. 420	20	0. 107	29. 464	60	0. 114	35. 896
60	0. 101	23. 521	18600	0. 107	29. 571	40	0. 115	36. 011
40	0. 101	23. 623	18580	0. 108	29. 679	20	0. 115	36. 126
20	0. 101	23. 724	60	0. 108	29. 787	17400	0. 115	36. 240
19700	0. 101	23. 826	40	0. 108	29. 894	17380	0. 115	36. 355
19680	0. 102	23. 927	20	0. 108	30. 002	60	0. 115	36. 471
60	0. 102	24. 029	18500	0. 108	30. 110	40	0. 115	36. 586
40	0. 102	24. 131	18480	0. 108	30. 219	20	0. 115	36. 701
20	0. 102	24. 232	60	0. 108	30. 327	17300	0. 116	36. 817
19600	0. 102	24. 334	40	0. 108	30. 435	17280	0. 116	36. 932
19580	0. 102	24. 437	20	0. 109	30. 544	60	0. 116	37. 048
60	0. 102	24. 539	18400	0. 109	30. 652	40	0. 116	37. 164
40	0. 102	24. 641	18380	0. 109	30. 761	20	0. 116	37. 280
20	0. 102	24. 743	60	0. 109	30. 870	17200	0. 116	37. 396
19500	0. 103	24. 846	40	0. 109	30. 979	17180	0. 116	37. 513
19480	0. 103	24. 949	20	0. 109	31. 088	60	0. 116	37. 629
60	0. 103	25. 051	18300	0. 109	31. 197	40	0. 117	37. 746
40	0. 103	25. 154	18280	0. 109	31. 307	20	0. 117	37. 863
20	0. 103	25. 257	60	0. 109	31. 416	17100	0. 117	37. 980
19400	0. 103	25. 360	40	0. 110	31. 526	17080	0. 117	38. 097
19380	0. 103	25. 463	20	0. 110	31. 635	60	0. 117	38. 214
60	0. 103	25. 567	18200	0. 110	31. 745	40	0. 117	38. 331
40	0. 103	25. 670	18180	0. 110	31. 855	20	0. 117	38. 448
20	0. 103	25. 773	60	0. 110	31. 965	17000	0. 118	38. 566
19300	0. 104	25. 877	40	0. 110	32. 075	16980	0. 118	38. 684
19280	0. 104	25. 980	20	0. 110	32. 186	60	0. 118	38. 802
60	0. 104	26. 084	18100	0. 110	32. 296	40	0. 118	38. 920
40	0. 104	26. 188	18080	0. 111	32. 407	20	0. 118	39. 038
20	0. 104	26. 292	60	0. 111	32. 517	16900	0. 118	39. 156
19200	0. 104	26. 396	40	0. 111	32. 628	16880	0. 118	39. 274
19180	0. 104	26. 501	20	0. 111	32. 739	60	0. 119	39. 393
60	0. 104	26. 605	18000	0. 111	32. 850	40	0. 119	39. 512
40	0. 104	26. 709	17980	0. 111	32. 961	20	0. 119	39. 631
20	0. 105	26. 814	60	0. 111	33. 073	16800	0. 119	39. 750
19100	0. 105	26. 919	40	0. 111	33. 184	16780	0. 119	39. 869
19080	0. 105	27. 023	20	0. 112	33. 296	60	0. 119	39. 988
60	0. 105	27. 128	17900	0. 112	33. 407	40	0. 119	40. 107
40	0. 105	27. 233	17880	0. 112	33. 519	20	0. 120	40. 227
20	0. 105	27. 338	60	0. 112	33. 631	16700	0. 120	40. 347
19000	0. 105	27. 444	40	0. 112	33. 743	16680	0. 120	40. 466
18980	0. 105	27. 549	20	0. 112	33. 855	60	0. 120	40. 586
60	0. 105	27. 654	17800	0. 112	33. 968	40	0. 120	40. 706
40	0. 106	27. 760	17780	0. 112	34. 080	20	0. 120	40. 827
20	0. 106	27. 865	60	0. 113	34. 193	16600	0. 120	40. 947
18900	0. 106	27. 971	40	0. 113	34. 305	16580	0. 121	41. 068
18880	0. 106	28. 077	20	0. 113	34. 418	60	0. 121	41. 188
60	0. 106	28. 183	17700	0. 113	34. 531	40	0. 121	41. 309
40	0. 106	28. 289	17680	0. 113	34. 644	20	0. 121	41. 430
20	0. 106	28. 395	60	0. 113	34. 757	16500	0. 121	41. 551

(H−h) ft.	Δp mm.	ΣΔp mm.	(H−h) ft.	Δp mm.	ΣΔp mm.	(H−h) ft.	Δp mm.	ΣΔp mm.
16480	0. 121	41. 673	15320	0. 130	48. 971	14160	0. 141	56. 845
60	0. 121	41. 794	15300	0. 131	49. 102	40	0. 141	56. 986
40	0. 122	41. 916	15280	0. 131	49. 233	20	0. 142	57. 128
20	0. 122	42. 037	60	0. 131	49. 364	14100	0. 142	57. 270
16400	0. 122	42. 159	40	0. 131	49. 495	14080	0. 142	57. 412
16380	0. 122	42. 281	20	0. 131	49. 626	60	0. 142	57. 554
60	0. 122	42. 403	15200	0. 131	49. 758	40	0. 142	57. 696
40	0. 122	42. 526	15180	0. 132	49. 889	20	0. 143	57. 839
20	0. 122	42. 648	60	0. 132	50. 021	14000	0. 143	57. 982
16300	0. 123	42. 771	40	0. 132	50. 153	13980	0. 143	58. 124
16280	0. 123	42. 894	20	0. 132	50. 285	60	0. 143	58. 268
60	0. 123	43. 017	15100	0. 132	50. 418	40	0. 143	58. 411
40	0. 123	43. 140	15080	0. 133	50. 550	20	0. 144	58. 555
20	0. 123	43. 263	60	0. 133	50. 683	13900	0. 144	58. 698
16200	0. 123	43. 386	40	0. 133	50. 816	13880	0. 144	58. 842
16180	0. 124	43. 510	20	0. 133	50. 949	60	0. 144	58. 987
60	0. 124	43. 633	15000	0. 133	51. 082	40	0. 144	59. 131
40	0. 124	43. 757	14980	0. 133	51. 216	20	0. 145	59. 276
20	0. 124	43. 881	60	0. 134	51. 349	13800	0. 145	59. 420
16100	0. 124	44. 005	40	0. 134	51. 483	13780	0. 145	59. 565
16080	0. 124	44. 130	20	0. 134	51. 617	60	0. 145	59. 711
60	0. 124	44. 254	14900	0. 134	51. 751	40	0. 145	59. 856
40	0. 125	44. 379	14880	0. 134	51. 885	20	0. 146	60. 002
20	0. 125	44. 504	60	0. 134	52. 020	13700	0. 146	60. 148
16000	0. 125	44. 628	40	0. 135	52. 155	13680	0. 146	60. 294
15980	0. 125	44. 754	20	0. 135	52. 290	60	0. 146	60. 440
60	0. 125	44. 879	14800	0. 135	52. 425	40	0. 147	60. 587
40	0. 125	45. 004	14780	0. 135	52. 560	20	0. 147	60. 733
20	0. 126	45. 130	60	0. 135	52. 695	13600	0. 147	60. 880
15900	0. 126	45. 255	40	0. 136	52. 831	13580	0. 147	61. 027
15880	0. 126	45. 381	20	0. 136	52. 967	60	0. 147	61. 175
60	0. 126	45. 507	14700	0. 136	53. 103	40	0. 148	61. 322
40	0. 126	45. 633	14680	0. 136	53. 239	20	0. 148	61. 470
20	0. 126	45. 768	60	0. 136	53. 375	13500	0. 148	61. 618
15800	0. 126	45. 886	40	0. 137	53. 512	13480	0. 148	61. 767
15780	0. 127	46. 013	20	0. 137	53. 648	60	0. 148	61. 915
60	0. 127	46. 140	14600	0. 137	53. 785	40	0. 149	62. 064
40	0. 127	46. 267	14580	0. 137	53. 922	20	0. 149	62. 213
20	0. 127	46. 394	60	0. 137	54. 059	13400	0. 149	62. 362
15700	0. 127	46. 521	40	0. 137	54. 197	13380	0. 149	62. 511
15680	0. 127	46. 649	20	0. 138	54. 335	60	0. 150	62. 661
60	0. 128	46. 776	14500	0. 138	54. 472	40	0. 150	62. 811
40	0. 128	46. 904	14480	0. 138	54. 610	20	0. 150	62. 961
20	0. 128	47. 032	60	0. 138	54. 749	13300	0. 150	63. 111
15600	0. 128	47. 160	40	0. 138	54. 887	13280	0. 150	63. 261
15580	0. 128	47. 288	20	0. 139	55. 026	60	0. 151	63. 412
60	0. 128	47. 417	14400	0. 139	55. 164	40	0. 151	63. 563
40	0. 129	47. 546	14380	0. 139	55. 303	20	0. 151	63. 714
20	0. 129	47. 674	60	0. 139	55. 443	13200	0. 151	63. 866
15500	0. 129	47. 803	40	0. 139	55. 582	13180	0. 152	64. 017
15480	0. 129	47. 932	20	0. 140	55. 721	60	0. 152	64. 169
60	0. 129	48. 062	14300	0. 140	55. 861	40	0. 152	64. 321
40	0. 129	48. 191	14280	0. 140	56. 001	20	0. 152	64. 473
20	0. 130	48. 321	60	0. 140	56. 141	13100	0. 153	64. 626
15400	0. 130	48. 451	40	0. 140	56. 282	13080	0. 153	64. 779
15380	0. 130	48. 580	20	0. 141	56. 422	60	0. 153	64. 932
60	0. 130	48. 711	14200	0. 141	56. 563	40	0. 153	65. 085
40	0. 130	48. 841	14180	0. 141	56. 704	20	0. 153	65. 239

$(H-h)$ *ft.*	Δp *mm.*	$\Sigma\Delta p$ *mm.*
13000	0. 154	65. 392
12980	0. 154	65. 546
60	0. 154	65. 700
40	0. 154	65. 855
20	0. 155	66. 010
12900	0. 155	66. 164
12880	0. 155	66. 320
60	0. 155	66. 475
40	0. 156	66. 631
20	0. 156	66. 787
12800	0. 156	66. 943
12780	0. 156	67. 099
60	0. 157	67. 256
40	0. 157	67. 413
20	0. 157	67. 570
12700	0. 157	67. 727
12680	0. 158	67. 885
60	0. 158	68. 042
40	0. 158	68. 201
20	0. 158	68. 359
12600	0. 159	68. 518
12580	0. 159	68. 676
60	0. 159	68. 836
40	0. 159	68. 995
20	0. 160	69. 164
12500	0. 160	69. 314
12480	0. 160	69. 474
60	0. 160	69. 635
40	0. 161	69. 796
20	0. 161	69. 956
12400	0. 161	70. 118
12380	0. 161	70. 279
60	0. 162	70. 441
40	0. 162	70. 603
20	0. 162	70. 765
12300	0. 162	70. 927
12280	0. 163	71. 090
60	0. 163	71. 253
40	0. 163	71. 416
20	0. 164	71. 580
12200	0. 164	71. 744
12180	0. 164	71. 908
60	0. 164	72. 072
40	0. 165	72. 237
20	0. 165	72. 402
12100	0. 165	72. 567
12080	0. 165	72. 732
60	0. 166	72. 898
40	0. 166	73. 064
20	0. 166	73. 230
12000	0. 167	73. 397
11980	0. 167	73. 563
60	0. 167	73. 730
40	0. 167	73. 896
20	0. 168	74. 065
11900	0. 168	74. 233
11880	0. 168	74. 402
60	0. 168	74. 570
11840	0. 169	74. 739
20	0. 169	74. 908
11800	0. 169	75. 077
11780	0 170	75. 247
60	0. 170	75. 417
40	0. 170	75. 587
20	0. 170	75. 758
11700	0. 171	75. 928
11680	0. 171	76. 099
60	0. 171	76. 271
40	0. 172	76. 442
20	0. 172	76. 614
11600	0. 172	76. 787
11580	0. 173	76. 959
60	0. 173	77. 132
40	0. 173	77. 305
20	0. 173	77. 479
11500	0. 174	77. 652
11480	0. 174	77. 827
60	0. 174	78. 001
40	0. 175	78. 176
20	0. 175	78. 351
11400	0. 175	78. 526
11380	0. 176	78. 701
60	0. 176	78. 877
40	0. 176	79. 054
20	0. 177	79. 230
11300	0. 177	79. 407
11280	0. 177	79. 584
60	0. 177	79. 761
40	0. 178	79. 939
20	0. 178	80. 117
11200	0. 178	80. 296
11180	0. 179	80. 474
60	0. 179	80. 654
40	0. 179	80. 833
20	0. 180	81. 013
11100	0. 180	81. 193
11080	0. 180	81. 373
60	0. 181	81. 554
40	0. 181	81. 735
20	0. 181	81. 916
11000	0. 182	82. 097
10980	0. 182	82. 280
60	0. 182	82. 462
40	0. 183	82. 645
20	0. 183	82. 828
10900	0. 183	83. 011
10880	0. 184	83. 194
60	0. 184	83. 378
40	0. 184	83. 563
20	0. 185	83. 747
10800	0. 185	83. 932
10780	0. 185	84. 118
60	0. 186	84. 304
40	0. 186	84. 490
20	0. 186	84. 676
10700	0. 187	84. 863
10680	0. 187	85. 050
60	0. 187	85. 237
40	0. 188	85. 425
20	0. 188	85. 613
10600	0. 188	85. 802
10580	0. 189	85. 991
60	0. 189	86. 180
40	0. 190	86. 369
20	0. 190	86. 559
10500	0. 190	86. 750
10480	0. 191	86. 940
60	0. 191	87. 131
40	0. 191	87. 323
20	0. 192	87. 514
10400	0. 192	87. 707
10380	0. 192	87. 899
60	0. 193	88. 092
40	0. 193	88. 285
20	0. 194	88. 479
10300	0. 194	88. 673
10280	0. 194	88. 867
60	0. 195	89. 062
40	0. 195	89. 257
20	0. 196	89. 452
10200	0. 196	89. 648
10180	0. 196	89. 845
60	0. 197	90. 041
40	0. 197	90. 238
20	0. 197	90. 436
10100	0. 198	90. 634
10080	0. 198	90. 832
60	0. 199	91. 030
40	0. 199	91. 229
20	0. 199	91. 429
10000	0. 200	91. 629
9990	0. 100	91. 729
80	0. 100	91. 829
70	0. 100	91. 929
60	0. 100	92. 029
9950	0. 100	92. 130
40	0. 101	92. 230
30	0. 101	92. 331
20	0. 101	92. 432
10	0. 101	92. 533
9900	0. 101	92. 634
9890	0. 101	92. 735
80	0. 101	92. 836
70	0. 101	92. 937
60	0. 101	93. 038
50	0. 101	93. 140
40	0. 102	93. 241
30	0. 102	93. 343
20	0. 102	93. 445
10	0. 102	93. 547
9800	0. 102	93. 649
9790	0. 102	93. 751
80	0. 102	93. 853
70	0. 102	93. 955

$(H-h)$ *ft.*	Δp *mm.*	$\Sigma\Delta p$ *mm.*
9760	0.102	94.058
50	0.103	94.160
40	0.103	94.263
30	0.103	94.366
20	0.103	94.468
10	0.103	94.571
9700	0.103	94.674
9690	0.103	94.778
80	0.103	94.881
70	0.103	94.984
60	0.103	95.088
50	0.104	95.191
40	0.104	95.295
30	0.104	95.399
20	0.104	95.503
10	0.104	95.607
9600	0.104	95.711
9590	0.104	95.815
80	0.104	95.919
70	0.104	96.024
60	0.105	96.128
50	0.105	96.233
40	0.105	96.338
30	0.105	96.443
20	0.105	96.548
10	0.105	96.653
9500	0.105	96.758
9490	0.105	96.863
80	0.105	96.969
70	0.106	97.074
60	0.106	97.180
9450	0.106	97.286
40	0.106	97.391
30	0.106	97.497
20	0.106	97.604
10	0.106	97.710
9400	0.106	97.816
9390	0.106	97.923
80	0.107	98.029
70	0.107	98.136
60	0.107	98.245
50	0.107	98.349
40	0.107	98.456
30	0.107	98.564
20	0.107	98.671
10	0.107	98.778
9300	0.107	98.886
9290	0.108	98.993
80	0.108	99.101
70	0.108	99.209
60	0.108	99.317
50	0.108	99.425
40	0.108	99.533
30	0.108	99.641
20	0.108	99.750
10	0.109	99.858
9200	0.109	99.967
9190	0.109	100.075
9180	0.109	100.184
70	0.109	100.293
60	0.109	100.402
50	0.109	100.512
40	0.109	100.621
30	0.109	100.730
20	0.110	100.840
10	0.110	100.950
9100	0.110	101.060
9090	0.110	101.170
80	0.110	101.280
70	0.110	101.390
60	0.110	101.500
50	0.110	101.611
40	0.111	101.721
30	0.111	101.832
20	0.111	101.943
10	0.111	102.054
9000	0.111	102.165
8990	0.111	102.276
80	0.111	102.387
70	0.111	102.498
60	0.112	102.610
8950	0.112	102.722
40	0.112	102.833
30	0.112	102.945
20	0.112	103.057
10	0.112	103.170
8900	0.112	103.282
8890	0.112	103.394
80	0.113	103.507
70	0.113	103.620
60	0.113	103.732
50	0.113	103.845
40	0.113	103.958
30	0.113	104.072
20	0.113	104.185
10	0.113	104.298
8800	0.114	104.412
8790	0.114	104.526
80	0.114	104.639
70	0.114	104.753
60	0.114	104.867
50	0.114	104.982
40	0.114	105.096
30	0.114	105.210
20	0.115	105.325
10	0.115	105.440
8700	0.115	105.555
8690	0.115	105.670
80	0.115	105.785
70	0.115	105.900
60	0.115	106.016
50	0.116	106.131
40	0.116	106.247
30	0.116	106.363
20	0.116	106.478
10	0.116	106.595
8600	0.116	106.711
8590	0.116	106.827
80	0.116	106.944
70	0.117	107.060
60	0.117	107.177
50	0.117	107.294
40	0.117	107.411
30	0.117	107.528
20	0.117	107.645
10	0.117	107.763
8500	0.118	107.880
8490	0.118	107.998
80	0.118	108.116
70	0.118	108.234
60	0.118	108.352
50	0.118	108.470
40	0.118	108.589
30	0.119	108.707
20	0.119	108.826
10	0.119	108.945
8400	0.119	109.064
8390	0.119	109.183
80	0.119	109.302
70	0.119	109.422
60	0.120	109.541
50	0.120	109.661
40	0.120	109.781
30	0.120	109.901
20	0.120	110.021
10	0.120	110.141
8300	0.120	110.261
8290	0.121	110.382
80	0.121	110.503
70	0.121	110.624
60	0.121	110.745
50	0.121	110.866
40	0.121	110.987
30	0.121	111.108
20	0.122	111.230
10	0.122	111.352
8200	0.122	111.474
8190	0.122	111.596
80	0.122	111.718
70	0.122	111.840
60	0.122	111.963
50	0.123	112.085
40	0.123	112.208
30	0.123	112.331
20	0.123	112.454
10	0.123	112.577
8100	0.123	112.701
8090	0.124	112.824
80	0.124	112.948
70	0.124	113.072
60	0.124	113.196
50	0.124	113.320
40	0.124	113.444
30	0.124	113.568

(H—h) ft.	Δp mm.	ΣΔp mm.	(H—h) ft.	Δp mm.	ΣΔp mm.	(H—h) ft.	Δp mm.	ΣΔp mm.
8020	0. 125	113. 693	7440	0. 134	121. 199	6860	0. 146	129. 316
10	0. 125	113. 818	30	0. 134	121. 333	50	0. 146	129. 462
8000	0. 125	113. 943	20	0. 135	121. 468	40	0. 146	129. 608
7990	0. 125	114. 068	10	0. 135	121. 603	30	0. 146	129. 754
80	0. 125	114. 193	7400	0. 135	121. 739	20	0. 147	130. 901
70	0. 125	114. 318	7390	0. 135	121. 874	10	0. 147	130. 048
60	0. 126	114. 444	80	0. 135	122. 009	6800	0. 147	130. 195
50	0. 126	114. 570	70	0. 136	122. 145	6790	0. 147	130. 342
40	0. 126	114. 696	60	0. 136	122. 281	80	0. 147	130. 489
30	0. 126	114. 822	50	0. 136	122. 417	70	0. 148	130. 637
20	0. 126	114. 948	40	0. 136	122. 553	60	0. 148	130. 785
10	0. 126	115. 074	30	0. 136	122. 689	50	0. 148	130. 933
7900	0. 126	115. 201	20	0. 137	122. 826	40	0. 148	131. 081
7890	0. 127	115. 327	10	0. 137	122. 963	30	0. 148	131. 229
80	0. 127	115. 454	7300	0. 137	123. 100	20	0. 149	131. 378
70	0. 127	115. 581	7290	0. 137	123. 237	10	0. 149	131. 527
60	0. 127	115. 708	80	0. 137	123. 374	6700	0. 149	131. 677
50	0. 127	115. 836	70	0. 137	123. 511	6690	0. 149	131. 826
40	0. 127	115. 963	60	0. 138	123. 659	80	0. 150	131. 976
30	0. 128	116. 091	50	0. 138	123. 787	70	0. 150	132. 126
20	0. 128	116. 218	40	0. 138	123. 925	60	0. 150	132. 276
10	0. 128	116. 346	30	0. 138	124. 063	50	0. 150	132. 426
7800	0. 128	116. 475	20	0. 138	124. 201	40	0. 150	132. 576
7790	0. 128	116. 603	10	0. 139	124. 340	30	0. 151	132. 727
80	0. 128	116. 731	7200	0. 139	124. 479	20	0. 151	132. 878
70	0. 129	116. 860	7190	0. 139	124. 618	10	0. 151	133. 029
60	0. 129	116. 989	80	0. 139	124. 757	6600	0. 151	133. 180
50	0. 129	117. 118	70	0. 139	124. 896	6590	0. 152	133. 332
40	0. 129	117. 247	60	0. 140	125. 036	80	0. 152	133. 484
30	0. 129	117. 376	50	0. 140	125. 176	70	0. 152	133. 636
20	0. 129	117. 505	40	0. 140	125. 316	60	0. 152	133. 788
10	0. 130	117. 635	30	0. 140	125. 456	50	0. 153	133. 941
7700	0. 130	117. 765	20	0. 140	125. 596	40	0. 153	134. 094
7690	0. 130	117. 895	10	0. 141	125. 737	30	0. 153	134. 247
80	0. 130	118. 025	7100	0. 141	125. 878	20	0. 153	134. 400
70	0. 130	118. 155	7090	0. 141	126. 019	10	0. 153	134. 553
60	0. 130	118. 286	80	0. 141	126. 160	6500	0. 154	134. 707
50	0. 131	118. 416	70	0. 141	126. 301	6490	0. 154	134. 861
40	0. 131	118. 547	60	0. 142	126. 443	80	0. 154	135. 015
30	0. 131	118. 678	50	0. 142	126. 585	70	0. 154	135. 169
20	0. 131	118. 809	40	0. 142	126. 727	60	0. 155	135. 324
10	0. 131	118. 941	30	0. 142	126. 869	6450	0. 155	135. 479
7600	0. 131	119. 072	20	0. 142	127. 011	40	0. 155	135. 634
7590	0. 132	119. 204	10	0. 143	127. 154	30	0. 155	135. 789
80	0. 132	119. 336	7000	0. 143	127. 296	20	0. 156	135. 945
70	0. 132	119. 468	6990	0. 143	127. 439	10	0. 156	136. 101
60	0. 132	119. 600	80	0. 143	127. 582	6400	0. 156	136. 257
50	0. 132	119. 732	70	0. 143	127. 725	6390	0. 156	136. 413
40	0. 133	119. 865	60	0. 144	127. 869	80	0. 157	136. 570
30	0. 133	119. 997	6950	0. 144	128. 013	70	0. 157	136. 727
20	0. 133	120. 130	40	0. 144	128. 157	60	0. 157	136. 884
10	0. 133	120. 263	30	0. 144	128. 301	50	0. 157	137. 041
7500	0. 133	120. 397	20	0. 144	128. 445	40	0. 158	137. 199
7490	0. 133	120. 530	10	0. 145	128. 590	30	0. 158	137. 357
80	0. 134	120. 664	6900	0. 145	128. 735	20	0. 158	137. 515
70	0. 134	120. 797	6890	0. 145	128. 880	10	0. 158	137. 673
60	0. 134	120. 931	80	0. 145	129. 025	6300	0. 159	137. 832
7450	0. 134	121. 065	70	0. 145	129. 170	6290	0. 159	137. 991

$(H-h)$ ft.	Δp mm.	$\Sigma\Delta p$ mm.	$(H-h)$ ft.	Δp mm.	$\Sigma\Delta p$ mm.	$(H-h)$ ft.	Δp mm.	$\Sigma\Delta p$ mm.
6280	0. 159	138. 150	5850	0. 171	145. 243	5420	0. 184	152. 877
70	0. 159	138. 309	40	0. 171	145. 414	10	0. 185	153. 062
60	0. 160	138. 469	30	0. 171	145. 585	5400	0. 185	153. 247
50	0. 160	138. 629	20	0. 172	145. 757	5390	0. 185	153. 432
40	0. 160	138. 789	10	0. 172	145. 929	80	0. 186	153. 618
30	0. 160	138. 949	5800	0. 172	146. 101	70	0. 186	153. 804
20	0. 161	139. 110	5790	0. 173	146. 274	60	0. 186	153. 990
10	0. 161	139. 271	80	0. 173	146. 447	50	0. 187	154. 177
6200	0. 161	139. 432	70	0. 173	146. 620	40	0. 187	154. 364
6190	0. 161	139. 593	60	0. 173	146. 793	30	0. 187	154. 552
80	0. 162	139. 755	50	0. 174	146. 967	20	0. 188	154. 739
70	0. 162	139. 917	40	0. 174	147. 141	10	0. 188	154. 928
60	0. 162	140. 079	30	0. 174	147. 315	5300	0. 188	155. 116
50	0. 162	140. 241	20	0. 175	147. 490	5290	0. 189	155. 305
40	0. 163	140. 404	10	0. 175	147. 665	80	0. 189	155. 494
30	0. 163	140. 567	5700	0. 175	147. 840	70	0. 190	155. 684
20	0. 163	140. 730	5690	0. 176	148. 016	60	0. 190	155. 874
10	0. 164	140. 894	80	0. 176	148. 192	50	0. 190	156. 064
6100	0. 164	141. 058	70	0. 176	148. 368	40	0. 191	156. 255
6090	0. 164	141. 222	60	0. 177	148. 545	30	0. 191	156. 446
80	0. 164	141. 386	50	0. 177	148. 722	20	0. 191	156. 637
70	0. 165	141. 551	40	0. 177	148. 899	10	0. 192	156. 829
60	0. 165	141. 716	30	0. 177	149. 076	5200	0. 192	157. 021
50	0. 165	141. 881	20	0. 178	149. 254	5190	0. 192	157. 213
40	0. 165	142. 046	10	0. 178	149. 432	80	0. 193	157. 406
30	0. 166	142. 222	5600	0. 178	149. 610	70	0. 193	157. 599
20	0. 166	142. 378	5590	0. 179	149. 789	60	0. 194	157. 793
10	0. 166	142. 544	80	0. 179	149. 968	50	0. 194	157. 987
6000	0. 167	142. 711	70	0. 179	150. 147	40	0. 194	158. 181
5990	0. 167	142. 878	60	0. 180	150. 327	30	0. 195	158. 376
80	0. 167	143. 045	50	0. 180	150. 507	20	0. 195	158. 571
70	0. 167	143. 212	40	0. 180	150. 687	10	0. 196	158. 767
60	0. 168	143. 380	30	0. 181	150. 868	5100	0. 196	158. 963
5950	0. 168	143. 548	20	0. 181	151. 049	5090	0. 196	159. 159
40	0. 168	143. 716	10	0. 181	151. 230	80	0. 197	159. 356
30	0. 168	143. 884	5500	0. 182	151. 412	70	0. 197	159. 553
20	0. 169	144. 053	5490	0. 182	151. 594	60	0. 197	159. 750
10	0. 169	144. 222	80	0. 182	151. 776	50	0. 198	159. 948
5900	0. 169	144. 392	70	0. 183	151. 959	40	0. 198	160. 146
5890	0. 170	144. 562	60	0. 183	152. 142	30	0. 199	160. 345
80	0. 170	144. 732	50	0. 183	152. 325	20	0. 199	160. 544
70	0. 170	144. 902	40	0. 184	152. 509	10	0. 199	160. 743
60	0. 170	145. 072	30	0. 184	152. 693	5000	0. 200	160. 943

(2) *Use of parallax table.*—Let it be assumed that the photographs under consideration are essentially verticals and have the following characteristics:

Example 1. True altitude of flight $H=24{,}000$ feet.
Measured stereoscopic base $B_m=53.3$ millimeters.

(The above condition applies to photographs made with the center chamber of the T–3A aerial camera at 24,000 feet.) Assume further that elevations within the overlap of the photographs range substantially between 200 and 1,400 feet. It is desired to contour these photographs with a contour interval of 100 feet. It is therefore necessary to determine the parallax difference for intervals of 100 feet between the limits of 200 and 1,400 feet. From the conditions under which the photographs were taken: $(H-h)_{200}=24{,}000-200=23{,}800$ feet.

Entering the table in column (3) opposite the value $(H-h)=23{,}800$ feet,

$$p_{200}=4.919$$

For $(H-h)_{300}=23{,}700$ $\quad p_{300}=5.340$

$$p_{300}-p_{200}=5.340-4.919=0.421 \quad \text{(mm.)}$$

This is the sum of the values of Δp in column (2) of the table, between the values of $(H-h)=23{,}800$ and 23,700.

This value of $p=0.421$ is the value of parallax difference corresponding to $B_m=100$ millimeters. Multiplying this value by .533 gives $\Delta\ p=.224$ millimeter, which is the change in parallax between points whose elevations are 200 feet and 300 feet on the photographs under consideration.

Had the limits of the stereoscopic measurement permitted contouring with an interval of 20 feet, the values Δp corresponding to a change in elevation of 20 feet at $(H-h)=23{,}800$ could have been taken directly from the table (0.84), which when multiplied by .533 gives .045 millimeter. This is less than the smallest consistent reading of parallax difference, which for the average operator is about 0.05 millimeter, and contouring with such a small interval between contours should not be attempted.

Example 2. $H=9{,}800$ feet.
$B_m=70$ millimeters.
Range of elevations: between 400 and 950 feet.

It is desired to contour with an interval of 20 feet.

$$(H-h)_{400}=9{,}800-400=9{,}400$$
$$\Delta p_{400-420}=\Delta p_{9400-9380}=0.213$$
$$\Delta p_{420-440}=\Delta p_{9380-9360}=0.214$$
$$\Delta p_{440-460}=\Delta p_{9360-9340}=0.213$$
etc.

For use with $B_m=70$ millimeters, the above values of Δp must be multiplied by 0.70, which gives the following changes in parallax between contours for the photographs under consideration:

$$\Delta p_{400-420}=.149$$
$$\Delta p_{420-440}=.150$$
$$\Delta p_{440-460}=.149$$

The parallax values for the other contours are obtained in a similar manner. As will be explained in *g* (13), (14), and (15) below, a table should be compiled for each pair of photographs showing the changes of parallax corresponding to the various contours. This table should be prepared by the computing section in a large organization and by the stereo-comparagraph operator in a small unit. The process of applying these values of parallax to actual photographs and to the stereo-comparagraph is explained in detail in *g* and *h* below.

f. Spot elevations for contouring.—In *d* above, the impracticability of contouring from one known elevation was mentioned. As the axis of the camera is almost never vertical, every photograph has some tilt or tip or both. Operation of the stereo-comparagraph over photographs adjusted as in *c* above produces form lines based approximately on a plane parallel to the mean of the separate planes of the two photographs. The result is modified by change of scale due to varying plane altitudes, distortion of photographic materials, etc. In many cases, correction of some of the aberrations can be effected by slight changes in the position of the right-hand photograph. Such changes are not effective against distortion due to tip, in line of flight, or some combinations of other defects. Test readings are taken on several points of known elevation marked in the overlap. The points should be definite and clear so that the floating marks may be accurately fused on them. Road intersections make good points, while timber-covered hills are difficult to use. The mean results are tabulated and a graph (fig. 174), of corrections is prepared, applicable to certain areas of the overlap, as will be explained below. The object of the graph is to indicate changes in the micrometer settings as the work progresses over the

overlap, so that the lines will asume the position and form of contours, parallel to a datum plane based on mean sea level. In many cases, readings on four spot elevations, one near each corner, are sufficient for the construction of an excellent graph for that particular position of the photographs. At times adverse combinations of effects necessitate readings from eight or more spot elevations. The ideal distribution is indicated in figure 172. These elevations may be obtained by field

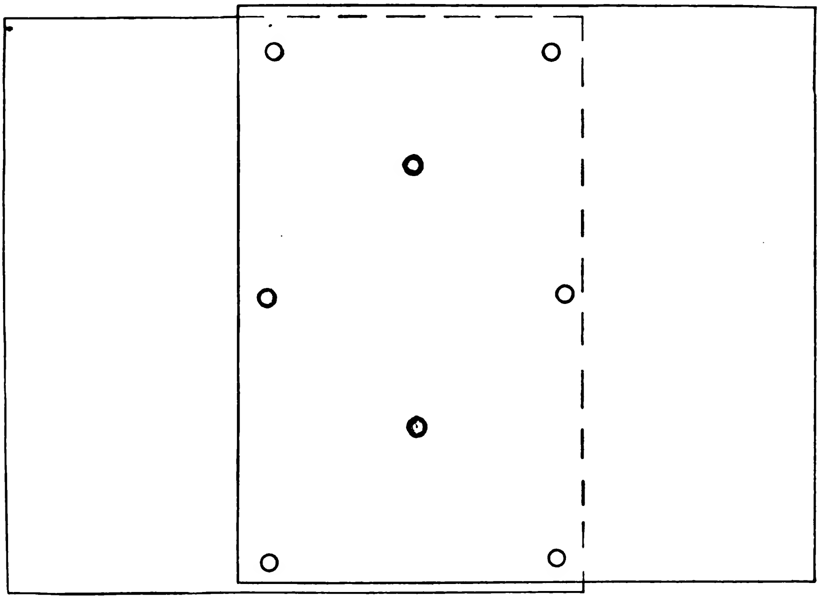


FIGURE 172.—Spot elevations for making graph.

work, from available maps, or from multiplex aero-projector data. If the latter are available, all eight elevations are determined for every overlap, as that arrangement of spot elevations will almost invariably give a graph which will keep vertical errors within the allowance. By choosing elevation points along the border of the area of overlap and marking them as outlined above, the topography may be extended through successive photographs for the compilation of maps of large areas, employing the same three spot elevations in two adjoining overlaps.

g. Graph construction.—(1) Set up stereo-comparagraph and adjust photographs as described in *c* above.

(2) Determine mean length of stereoscopic base of the two photographs in millimeters. (The scale on the back of the stereo-comparagraph may be used for this purpose.)

(3) Record this value of B_m either on a clean sheet of paper or on a form similar to that shown in figure 173, whereon should be recorded the quadrangle or project, photograph numbers, flight altitude, date, camera, etc. These should be preserved until the stereo-sketch has been compiled onto the map sheet. The flight altitude may be obtained from the data sheet which accompanied the photographs, or compute $H-h$ by dividing the focal length in feet by the representative fraction of the photographs.

(4) In column (4) list elevations of all known points.

(5) In column (1) obtain values of $(H-h)$ by subtracting known elevations from flight altitude.

(6) In column (2) record values of parallax ($\Sigma\Delta p$) from parallax tables in *e* above, corresponding to values of $(H-h)$.

(7) Subtract values of parallax corresponding to known elevations from parallax corresponding to $(H-h)$ when $h=0$, and record these values in column (3). These values are the parallax differences between sea level and the known elevations when $B_m=100$.

(8) Multiply values of column (3) by $B_m/100$ of photographs. Record these values in column (5).

(9) Fuse floating mark on points of known elevation and obtain micrometer readings for these points. (A mean of several readings should be taken.) Record these values in column (6).

(10) Add values of column (5) to (or *if zero of micrometer scale is at right, subtract values of column (5) from*) corresponding value of column (6) and thereby obtain parallax reading corresponding to points on sea level datum directly under known points. If there is no tip, tilt, or distortion the values of column (7) will be equal within the ability to read the instrument, or to the accuracy of the elevations of the known points. The differences in these values represent deformation of the sea level datum of the stereoscopic model due to the above discrepancies.

(11) The sea level micrometer values should now be compared to ascertain whether or not the graph lines might be materially simplified. If, for example, the sea level values for the points at the top of the overlap are greater than those in the middle, and those at the bottom are less than in the middle, the differences can be reduced by rotating the right-hand print enough to equalize all values. The movement will be very small, as 0.01 inch equals 0.25 millimeter. At the top and bottom edges mark continuous ticks on photograph and mount; stick a No. 10 needle vertically through point selected as center of rotation, turn photograph by amount estimated as necessary to bring sea level values into better agreement, and secure the

photograph. Record new mean micrometer readings for all elevation points and deduce new sea level values. The graph in figure 174 has 16 correction lines; if the right-hand photograph had been

Project LONGVIEW
Quadrangle LA CENTER
Photograph Nos. B-452,453
Operator JOHN DOE
Photo. Scale 1:31,250
Date 1/19/40
Flight Altitude (H) = 16,000 FT.
Time FOR COMPLETING SKETCH 7 HRS.
B_m = 51.2mm
Camera T-3A

1	2	3	4	5	6	7
H-h	$\Sigma\Delta p$	Δph	h	$\frac{\Delta ph \times B_m}{100}$	Micrometer reading	Micro. reading to sea level
16,000	44.63	--	0			
15,156	50.05	5.42	844	2.78	12.78	15.56
15,190	49.82	5.19	810	2.66	12.70	15.36
15,037	50.84	6.21	963	3.18	11.90	15.08
15,086	50.51	5.88	914	3.01	12.43	15.44
15,194	49.80	5.17	806	2.65	12.57	15.22
15,155	50.06	5.43	845	2.78	12.33	15.11
14,330	55.65	11.02	1670	5.64	10.20	15.84
14,891	51.81	7.18	1109	3.68	11.87	15.55
14,826	52.25	7.62	1174	3.90	11.29	15.17
16,000	44.63	--	0			
15,400	48.45	3.82	600	1.96		
15,300	49.10	4.47	700	2.29		
15,200	49.76	5.13	800	2.63		
15,100	50.42	5.79	900	2.96		
15,000	51.08	6.45	1000	3.30		
14,900	51.75	7.12	1100	3.65		
14,800	52.43	7.79	1200	3.99		
14,700	53.10	8.47	1300	4.34		
Etc.			Etc.			

FIGURE 173.—Specimen form for graph computation.

turned 0.01-inch or a little more, only six or eight correction lines would have been required. As the operator gains experience he will discover other ways of simplifying the graphs. Once the position of the photographs is satisfactory, the right-hand one should be

permanently secured, with every precaution to avoid the slightest change in its position. Near the margin of the prints, a line should be drawn along the edge of the scale at the back of the stereo-comparagraph to simplify resetting the instrument in case work on the pair should be interrupted. If the contours cannot be completed in one work period, the micrometer readings in column (6) should be repeated and a new graph drawn if any material discrepancy is discovered.

(12) Using the values of column (7), figure 173, a graph is constructed as shown in figure 174, showing the parallax reading on the stereo-comparagraph corresponding to sea level datum under any point of the overlap. The graph might be drawn on the paper which is secured under the pencil of the drawing attachment to receive the contours. It is more convenient to have the lines on the face of the left-hand photograph, which is constantly under the eye of the operator as he moves the floating mark over the model. In the latter case, when the dot touches one of the graph lines, he may change the micrometer setting and continue along the contour without changing his position. The nearest foot of elevation is marked on the left photograph beside each circle, but the parallax readings for points are not so recorded as they would only obscure detail. To simplify drawing the graph, a rough tracing may be made of the circles and elevations, and the parallax readings may be placed thereon. This tracing may be used for a first draft of the graph lines which are interpolated between the micrometer readings by estimation, in a manner similar to that of sketching logical contours between critical points, where the slope is assumed to be uniform. The graph lines should be smooth and follow a definite pattern. Abrupt breaks or changes in form of the graph lines indicate an error of some sort. When such exists, the observations, computation, and elevations should be checked. If the error cannot be isolated, the point causing the break should be eliminated and disregarded for further work.

(13) On the form (fig. 173) in column (4) record values of contours likely to appear on photographs, subtract them from flight altitude, and record them in column (1) as values of $(H-h)$.

(14) From the parallax tables obtain values of parallax for contours as for known elevations of (6) above and subtract these for value of parallax when $h=0$.

(15) Multiply values of column (3) by $B_m/100$ and obtain parallax difference for the several contours. Record these values in column (5).

h. Contouring with correction graph (fig. 175).—(1) Examine stereoscopic model and select area to be contoured first. It is usually better to plot the lowest contours first. When the lowest area has been found, set micrometer at a value corresponding to graph line nearest this point, and subtract from, or if zero of micrometer scale

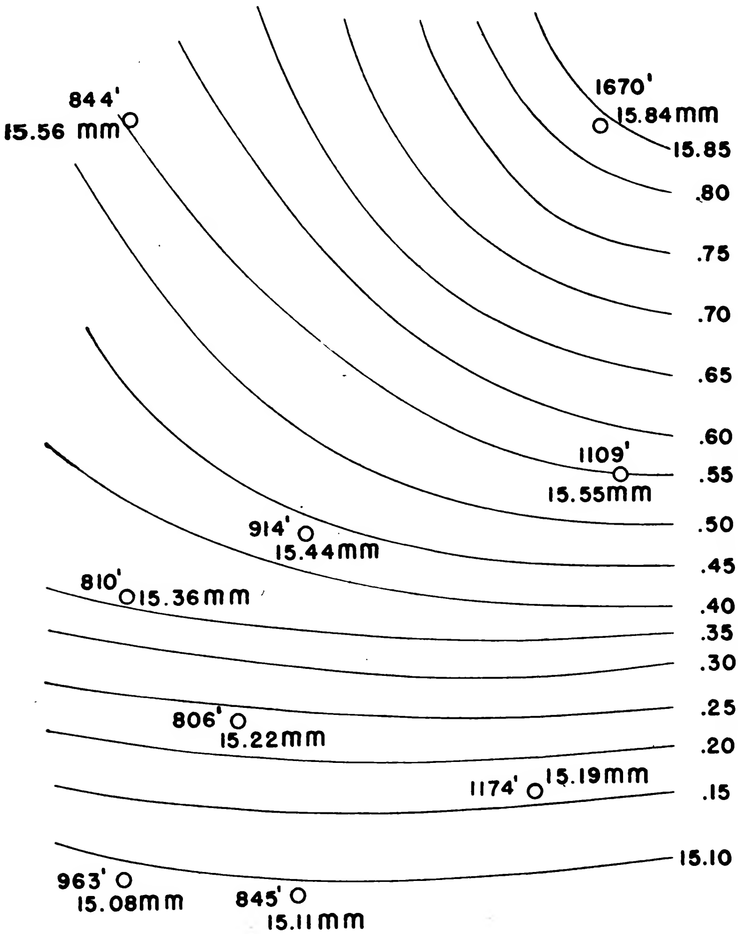


FIGURE 174.—Typical correction graph.

is at right add to this reading the value of parallax difference (column (5)) corresponding to desired contour and scan model along this line until fused image (floating mark) is brought into contact with ground.

(2) Lower pencil, move instrument over model, maintaining floating mark on ground. When graph lines of higher value than that

used as an origin are crossed, increase micrometer reading by 0.05 millimeter for each such line, and when a graph line is crossed in a decreasing direction the micrometer reading should be decreased by 0.05 millimeter. In this manner the contours are held as lines of (approximately within + or − 0.05 mm.) equal elevation above the sea level datum even though the sea level datum is distorted due to tip, tilt, or scale distortion, and the entire area of overlap may be worked without other adjustment.

(3) When the area of overlap has been contoured, the resulting stereo-sketch may be compiled into the map (par. 87) or used as otherwise intended. The planimetry will have been compiled directly from the photographs (par. 87). That operation is independent of contouring and is done in a large organization by draftsmen-compilers independently of the stereo-comparagraph operations. In order that the contours may be adjusted afterward to the compilation, all photographic control points should be transferred from the left-hand photograph to the contoured stereo-sketch. The right-hand mark glass may be turned up from the print during this part of the work. A few of the main planimetric features may also be transferred from the left-hand photograph, as further insurance that the contours will be compiled to fit the planimetry.

i. Contoured photographs.—The procedure for contouring photographs is the same as above except that the paper for receiving the contours is replaced by a print of the left-hand photograph, which has to be secured in such position that the pencil point falls on the same points as the left-hand mark in every part of the overlap. If provision is made in mounting the photographs, the entire area of the print may be contoured. This is accomplished by mounting the photograph to be contoured in the approximate center of a mounting sheet and mounting the overlapping prints to the right and the left thereof. To explain this procedure, let it be assumed it is desired to contour photograph B of a strip. Photographs A and C overlap the left and right halves of photograph B. Mount photographs B and C as specified in paragraph 88*c*. Without disturbing B and C, mount photograph A to the left of photograph B as for photograph C. Contour the area of B–C onto a transparent sheet, preferably film base. Take up mounted photographs, rotate them as a unit 180°, thereby causing photograph A to be to the right of photograph B, and adjust the partially completed stereo-sketch of area B–C under the pencil and contour area A–B. being careful properly to adjust to common control and to join the contour ends. In this manner the work is drawn to the scale of

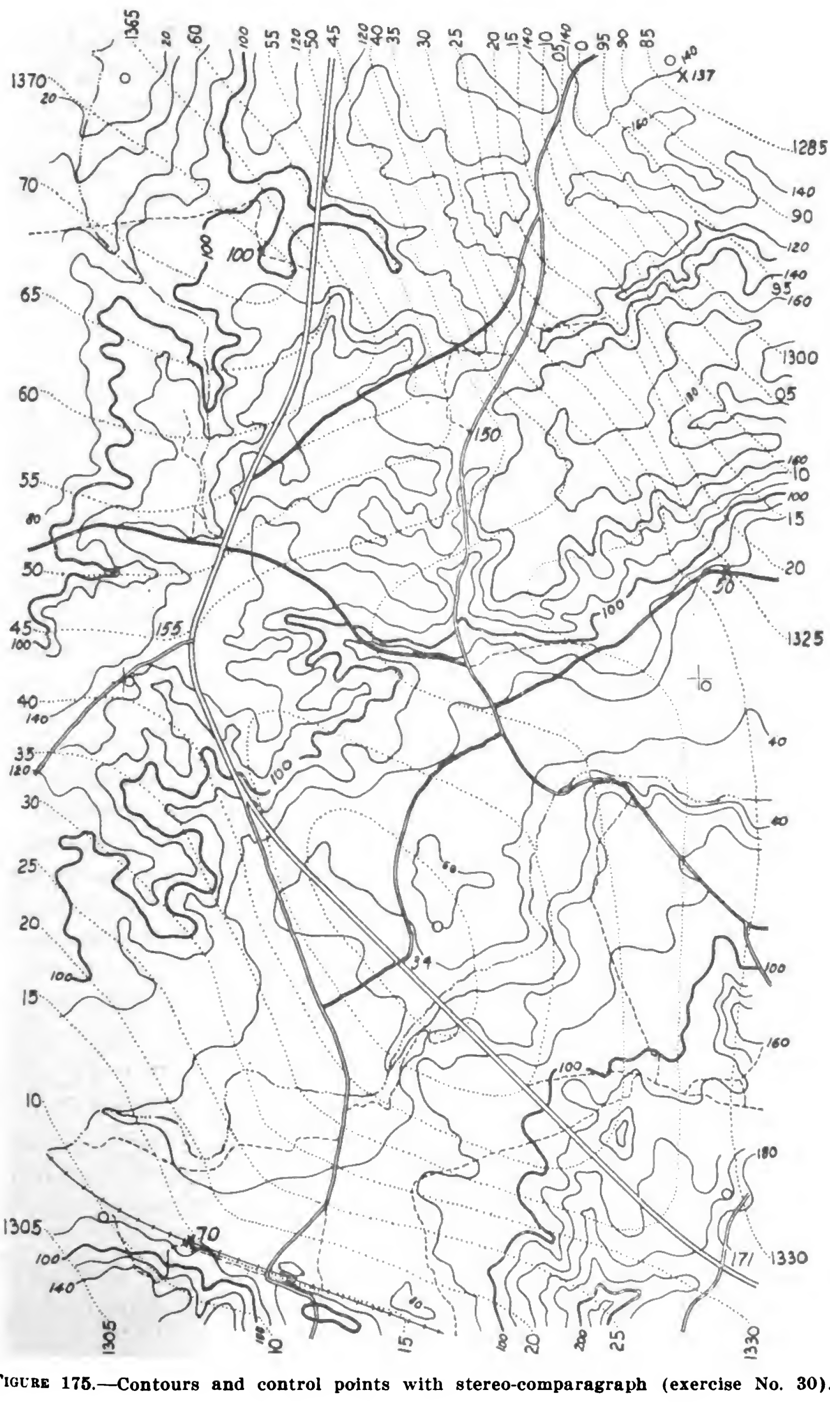


FIGURE 175.—Contours and control points with stereo-comparagraph (exercise No. 30).

photograph B, and when the transparent stereo-sketch is placed over photograph B and observed under a stereoscope, the contour lines will be seen to lie on the surface of the stereoscopic model. For reproduction the stereo-sketch may be overprinted with the negative of B; it may be placed over photograph B and copied; or the contours may be drawn directly on a duplicate print of B.

j. Exercise No. 30: contouring with stereo-comparagraph.—With the stereo-comparagraph, contour several successive overlaps of the photographs utilized in exercises Nos. 28 and 29. As the contours from these stereo-sketches will be compiled in exercise No. 31, the photographic control points and a few of the prominent topographic features should be transferred from the left-hand photograph as shown in figure 175. To gain facility with the stereo-comparagraph, several overlaps of varying terrain should be contoured, as a preliminary to the work assigned for the exercise.

k. Exercise No. 31: compiling stereo-comparagraph contours.—Observing the principles of paragraphs 87 and 88, adjust and transfer the contours drawn in exercise No. 30 to the planimetric compilation prepared in exercise No. 29. Preparatory to this exercise, several of the practice stereo-sketches drawn in exercise No. 30 should be adjusted and compiled on a practice sheet. (See fig. 178.)

89. Topography with multiplex aero-projector.—*a. Operation of reduction printer.*—As the success of the multiplex operation depends largely on the quality of the diapositives, it behooves the operator to take the utmost care to obtain the best possible results. The accuracy of the final work will be poor and the time necessary for its completion can be doubled by poor photo technique in the use of the multiplex reducing printer. Before drawing can be undertaken, the diapositives are inserted in the projectors and preparations are completed in the following order:

Interior orientation.
Relative orientation.
Absolute orientation.
Determination of vertical scale and contour interval.

(1) *Interior orientation.*—This consists in centering the diapositive in the projector by bringing into coincidence the two collimating marks which indicate the centers of the focal plane glass plate and the principal point of the diapositive.

(2) *Relative orientation.*—This is the adjustment of successive diapositives with respect to each other to produce a spacial model of

the field of overlap of the diapositives. Following are the six elements of relative orientation:

Movement of individual projectors in direction of *X*-ordinate.
Same for *Y*-ordinate.
Same for *Z*-ordinate.
Effect of swing of individual projectors.
Adjustment of tip on Cardan camera suspension.
Adjustment of tilt.

(3) *Absolute orientation.*—(*a*) Adjusting the scale of the model to the scale of the projection is done by increasing or decreasing the *bx* distances between the individual projectors and correcting any new vertical parallaxes induced by these changes.

(*b*) Leveling the model is done by adjusting the foot screws of the supports until the control points plotted on the drawing sheet agree absolutely with their projected positions obtained from the control stands by keeping the index marks thereof at the proper height and in contact with the images of the control points in the adjusted spacial model.

(4) *Determination of scale and contour interval.*—When properly adjusted, the spacial model is a small scale reduction of the landscape photographed. For the vertical scale it is advisable to compile a table which is the scale in nature multiplied by the RF of the plotting scale and tabulated according to differences of elevation as multiples of the chosen contour interval.

b. Method of drawing.—(1) In the compilation of planimetry, the floating mark is maintained in contact with the feature being compiled by means of an adjusting screw on the tracing stand (5) in figure 167, which is moved about over the surface of the drawing. Directly beneath the floating mark is a pencil for transferring onto the projection sheet a trace of the movement of the floating mark. Thus, when the drawing table is moved about the spacial model with the floating mark always in contact with it, the pencil traces onto the projection sheet a true orthographic projection of the features depicted in the spacial model, automatically correcting any change of scale due to relief. The model contains no tilt or relief distortion or change of scale due to varying flight altitudes. (See fig. 176.)

(2) In contouring, the floating mark is set at the prescribed elevation according to the scale of the model and the scale on the tracing stand, and is moved about in contact with the spacial model as each successive contour is searched out. The pencil mounted directly beneath the floating mark traces the contour line.

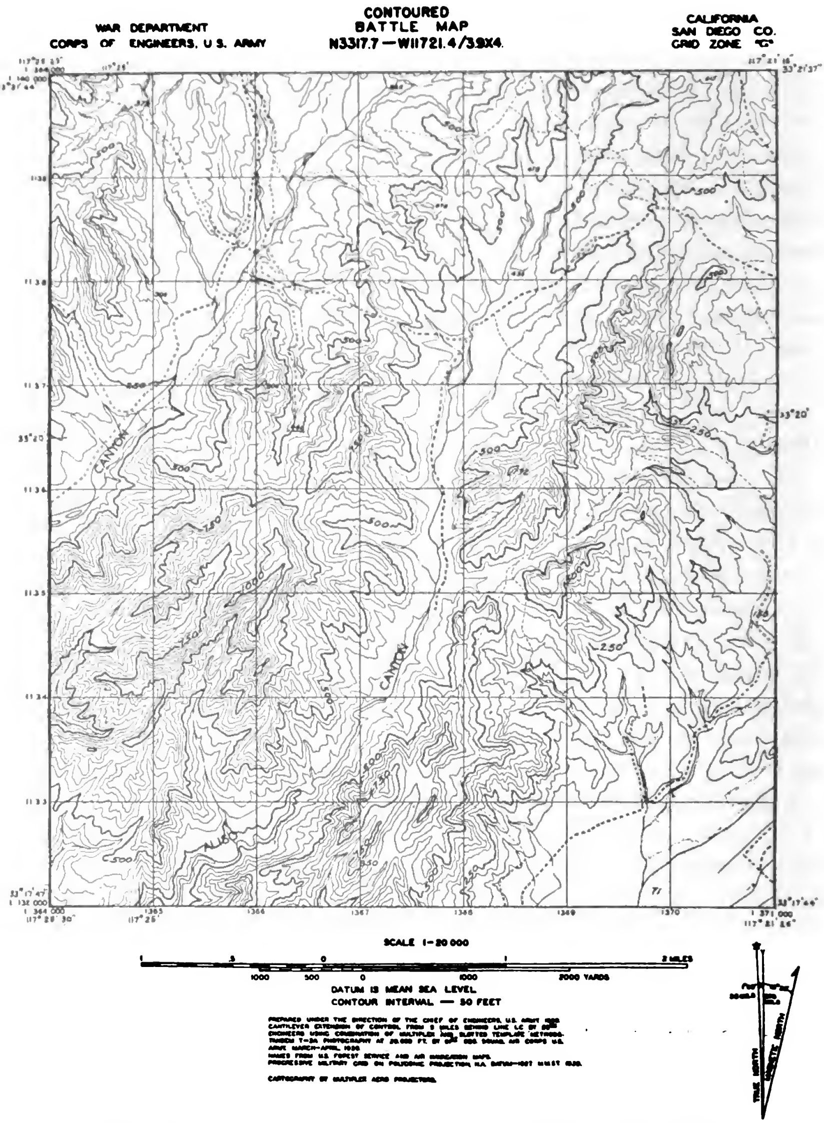


FIGURE 176.—Contours and planimetry with multiplex aero-projector.

Section XIX

PROVISIONAL AND BATTLE MAPS FROM PHOTOGRAPHS

90. Maps and map substitutes.—*a. General.*—Maps for use in the theater of operations naturally fall into classification according to scale. (See par. 43.) The use of the various maps will depend upon the character of the theater of operations, type of operations, and nature of opposition encountered. Maps for the theater of operations will include—

(1) Small scale maps for general planning and strategic studies by commanders of large units.

(2) Intermediate scale maps for planning operations, including movement, concentration, and supply of troops.

(3) Medium scale maps for strategical, tactical, and administrative studies by units ranging in size from the corps to the regiment.

(4) Large scale maps for the technical and tactical battle needs of the Field Artillery and of the Infantry, which may consist of any of the following maps:

Detailed battle maps—contoured or uncontoured.
Map substitutes—provisional maps and photomaps.

FM 30-20 lists the type of maps for the theater of operations in the United States, giving the scale, source, method of reproduction, and probable time or conditions of availability. A table included in that manual also indicates the military purposes of each type and under what conditions it may be most useful.

b. Classification according to scale.—(1) *Small scale map.*—These maps vary in scale from 1:1,000,000 to 1:7,000,000 and consist of various general maps compiled from source material. They furnish only general information of large areas, normally giving planimetric detail only.

(2) *Intermediate scale map.*—These vary in scale from 1:200,000 to 1:500,000 and furnish general information of large areas, showing the cities, towns, highways, railways, rivers, canals, bodies of water, and mountain ranges. The entire theater will be covered by a few sheets, which may be prepared from existing maps prior to hostilities. These maps are compiled and reproduced at base printing plants or by the GHQ topographic battalion.

(3) *Medium scale map.*—These maps vary in scale from 1:50,000 to 1:125,000. The U. S. Geological Survey map, scale 1:62,500, with wooded areas and road classifications added, has been found to be the most suitable map of this scale covering the United States. These maps show culture and drainage in considerable detail and are contoured at intervals appropriate to the topography. The ends of the 5,000 military grid lines are shown by ticks. When the road classification, wooded areas, and other military information are not overprinted, draftsmen may be called upon to prepare originals for such overprinting. Limited stocks of the U. S. Geological Survey maps are maintained, and large editions can be printed by the base plants and the topographic units according to the anticipated requirements. Should the supply run short, very good copies in one color can be quickly reproduced by any organization having lithographic equipment of suitable plate size. Many of the Geological Survey's maps would have to be revised prior to their use, and much of the capacity of the base plants in the larger topographic units may have to be devoted to the preparation and revision of these maps. Many other Government agencies make maps which may be helpful in emergency, although the maps may be uncontoured. A few Federal activities have large stocks of aerial negatives which may be found useful in the event of an emergency.

(4) *Large scale map.*—The battle map has been designed to fulfill the requirements of a large scale map. It is unlikely that maps of this category will be found to cover extensive areas. These maps are needed as soon as an actual contact is gained with the enemy and, when available, would normally have the widest distribution in combat. For limited areas, data secured for maps of the medium scale will be found suitable for enlargement in preparation of the large scale map. In general, large scale maps must be prepared by troops in the field for the area of immediate operation. They must be sufficiently detailed and of such accuracy that they may be used for the conduct of artillery fire with or without aerial observation. The ideal provision would cover the combat area and the flanks for many miles behind and beyond the battle lines with accurate, detailed, contoured, 1:20,000 battle maps based on a triangulation framework capable of extension over the whole theater of war. As the location cannot be determined until contact is made, and as the map is needed immediately, topographic units are organized and equipped for rapid preparation and reproduction of battle maps. Employing the nine-lens composites of 1:400,000 scale, the multiplex aerial projectors, stereo-comparagraphs, drafting and reproduction

methods designed for the most rapid progress consistent with the requisite quality, topographic battalions can deliver the 1:20,000 contoured battle maps of the first 100 square miles of the battle area within 2 weeks after receipt of photographs and over 100 square miles a day thereafter. Delivery of uncontoured battle maps can be made about 10 days earlier and also at a rate of considerably over 100 square miles per day, provided the personnel of the topographic battalions were not engaged in completing the contoured battle maps. In any event, battle maps will first be available only for the area of immediate and important operations. (See par. 91.) Some of the map substitutes which can be more quickly prepared are described in *c* to *g*, inclusive, below.

c. Progressive mapping program.—In order of probable availability, with estimated time of delivery after photography, this program provides for the following:

(1) Single verticals	3 to 48 hours.
(2) Strip mosaics (par. 41)	24 hours.
(3) Composite photographs	24 to 48 hours.
(4) Provisional maps, planimetric	24 to 48 hours.
(5) Mosaics, uncontrolled (par. 42).	24 to 48 hours.
(6) Mosaics, controlled (par. 101)	2 or more days, depending on quality.
(7) Provisional map with form lines.	48 to 72 hours.
(8) Uncontoured battle map	4 days.
(9) Provisional map with rough contours.	3 to 6 days.
(10) Contoured battle map	2 weeks or more (in progressive stages somewhat sooner).

NOTE.—Contoured topographical maps, 1:62,500, have been omitted as they may be rapidly reproduced if the copy is ready, but necessity of revision or complete preparation might greatly increase the time. As a rule, these medium-scale maps would be prepared for large areas of the theater of war before any major engagements take place. In the following discussion, it is assumed that the 1:62,500 maps have been published and that maps of larger scales have not.

d. Single verticals.—Taken by observation planes attached to each corps for intelligence and mapping purposes, these may be the first photomaps available to the combat troops. Prints 9 by 9 inch, 1:20,000 scale, include an area nearly 3 miles square, or 5 miles square at the smallest scale. Such photographs can be completely inter-

preted only by specially trained personnel. Rapid reproduction and distribution to the actual users will have to be arranged beforehand. Single verticals reproduced as photomaps will be marked as prescribed in paragraph 48*b*.

e. Strip mosaics.—These are prepared (par. 41) as an aid to the effective control of infantry and artillery fire, presumably on request of the units requiring them. Strip mosaics will be marked as described in paragraph 48*b*.

f. Composite photographs.—The 1:40,000 nine-lens type of composites, even when trimmed to the included square or to a 16- by 18-inch rectangle, will cover more ground area than the largest 1:20,000 contoured battle maps. The difficulties of interpretation are greatly increased by the small scale and the obliquity of images toward the edges. Confusion might arise from the fact that adjoining photographs overlap so that many areas appear on several different composites. The delay in production is caused by having to send the negatives from the Air Corps photo section to the topographical regiments, where they have to be printed in restitution printers, trimmed, mounted, marked, and photographically copied before quantity reproduction can be undertaken. The final reproduction will be by army or corps units according to circumstances. Composite photographs reproduced as photomaps will be marked as described in paragraph 48*b*.

g. Provisional maps.—(1) *General.*—These are not to be confused with battle maps prepared by the more precise and deliberate methods of paragraph 91. Provisional maps may be prepared from strips of single lens photographs taken by the corps planes or from any other strip photographs that may be available. Mounted nine-lens composites yield the quickest results. The hasty methods employed will preclude any correction of tilt and relief distortion. Provisional maps of small areas can be drafted and reproduced in planimetric form about as quickly as quantity reproduction of the component photographs can be accomplished. It is believed that such provisional maps will be more convenient for field use than a small collection of uninterpreted photographs which may show such a wealth of unimportant detail as to obscure the pertinent topographical features. Probably the best knowledge of the terrain might be obtained from a combined study of the best maps and photomaps available, especially if overlapping photographs and a stereoscope were used.

(2) *Preparation.*—The method involved can be more definitely outlined than that for hasty maps in paragraph 40. As provisional

maps may be needed frequently, and photographs and control data furnished will be somewhat similar in each case, suitable grids and stock marginal data borders and masks can be prepared in advance, and the entire procedure reduced to a standardized program to be varied as circumstances require. The possible later addition of the form lines and approximate contours must be kept in mind to fulfil orders for items (7) and (9) in *c* above. That list may indicate some duplication of work, which will be realized in some instances. Frequently the provisional maps, with or without form lines or contours, may be required for secondary army efforts, during the period when the topographical unit is concentrated on the main army effort.

(3) *Steps in the process.*—The stages of preparation of the provisional map, some of which should be carried on concurrently, will include the following:

(*a*) Rough lay-out of photographs.
(*b*) Selection of ground control points to be used.
(*c*) Determination of bounding grid lines.
(*d*) Determination of scale from best strip.
(*e*) Drafting grid and ground control points on film base.
(*f*) Marking photographs.
(*g*) Running center to center strips.
(*h*) Computing cutting points of meridian and parallel on bounding grid lines.
(*i*) Preparation of marginal data.
(*j*) Adjusting strips to control sheet.
(*k*) Tracing main road net to grid.
(*l*) Tracing details on grid.
(*m*) Preparation of rough lettering diagram.
(*n*) Lettering body of map.
(*o*) Inking roads, grid lines, and meridian and parallel.
(*p*) Editing.
(*q*) Preparing for reproduction.
(*r*) Checking proof.

(4) *Explanatory remarks.*—(*a*) The required photographs are selected from the file with the aid of the index map, arranged in numerical order, and laid out roughly in correct relation to each other. A few ground control points are identified and chalked on the top layer of prints. One of the middle strips which covers two control points is more carefully laid and scaled and the representative fraction calculated. If suitable measurements cannot be made, divide the focal length of the camera in feet by the net altitude of

the plane to get the RF, which must be known as accurately as possible before the grid is begun. The center-to-center control (par. 77) will be modified in that radial lines (par. 78) will fix the strip positions of all ground control points and tie points between strips for the first overlap and about every fifth overlap and the last one. There is no time for the complete employment of the radial line method. The selected tie points are chalked on the top layer. The ground control and tie points are pricked on all prints on which they appear and marked with red crayon, employing the stereoscope as in paragraph 75. The photographs are picked up in numerical order, and the center points are pricked and marked with crayon. The prints are prepared for the center-to-center method, and the required radial lines are drawn from the principal points at the same time as the center lines are drawn, with a sharp, wedge-pointed pencil if that will be legible through the film base. As the stereo-comparagraph may be employed later on, the principal points should be used rather than substitute centers which are not acceptable for stereo-comparagraph work. The center-to-center strips are now run, and the strip positions of the ground control and tie points are determined by radial line intersections.

(*b*) As soon as the RF has been determined, the standard military grid is prepared on film base. This stage must be completed rapidly so that the tracing of detail can be started without delay. If the average scale of the photographs is normally 1:20,000, a series of grids should be prepared in advance on metal-mounted sheets (par. 11*a*). A range from, say, 1:17,500 to 1:21,500 by increments of 500 in the denominator will take care of probable variations. In the worst case, a 250 discrepancy, the error will not exceed that caused by a moderate amount of tilt or relief distortion. To transfer the grid to the film base, secure the latter to the stock grid and prick the ends of all the lines to the film base. Lay the film base on the table and connect the points with carefully drawn straight pencil lines. This grid should be quickly checked by laying a steel straightedge through the corners of the 1,000-yard squares on two long diagonals. If there is no stock grid of suitable scale, one must be constructed accurately and quickly. (See par. 23*b*(1).) Number both ends of all grid lines in pencil, omitting 000. Plot the ground control points to be used (par. 67*d*) and have the plotting checked.

(*c*) The marginal data conforming with paragraph 48*a* are not drafted on the same piece of film base as the body of the map, but a separate stock border is altered to suit the work in hand and for-

warded to the reproduction section at an early stage so that they in turn may have the margin ready for plate making before the main tracing is received. The exact procedure depends upon the availability of a copying camera. If there is a camera, the tracing will be copied at the 1:20,000 scale. In that case, the stock borders are printed in advance on paper at the reproduction scale, including all the items of data (par. 48*a*) which may be repeated, and leaving blank the items which are different for each map, as index symbol, gisement diagram, designations of geographic and military grid lines, etc. Without a copying camera, the map will be reproduced to the scale of the compilation. The stock borders will have to be printed on film base, which must be cut and pasted with cellulose Scotch tape to fit the body of the map. In this case the yard and mile scales and representative fraction will have to be supplied unless a set is available from previous work. All other data will have to be inked on the film base border. The marginal data border is edited and sent to the reproduction section as soon as ready.

(*d*) The cutting points of the selected meridian and parallel can be determined on the stock sheet of the scale of reproduction. After checking, the two lines should be drawn on the body of the map.

(*e*) Adjusting the strips to the compilation sheet is accomplished in a manner similar to that prescribed in paragraph 78*n*, except that the tie points should be utilized as the extra points to be selected during adjustment. If the strips run beyond ground control, the strip which appears best to maintain the average scale of the photographs is used as the scale strip. The others are brought to the same scale by adjusting the strips successively through the tie points. As the azimuth of any strip is likely to be more nearly correct than the scale, exact scale adjustment of tie points may not be possible in all cases. If during the adjustment it becomes evident that the average scale of the photographs is more than 2 percent different from the scale of the compilation sheet, another compilation sheet of closer scale should be prepared. The center-to-center method does not provide any means of adjusting detail to overcome difference of scale. Once the adjustment is satisfactory, all control points should be circled and the center points numbered with photographic blue ink.

(*f*) In compiling detail, a network of the highways, railways, and other main topographic lines must be compiled first, and then subdivided by the addition of some secondary lines. This procedure is necessary because the photographic control points are so few that considerable adjustment may be required between overlapping photographs. Limiting the plotting of detail to the center of the print

where the distortions are least is more essential than with the radial-line method where wing points are plotted. Also it must be remembered that form lines or stereo-comparagraph contours may have to be added later. After the main and secondary nets have been penciled, the film base may be cut in quarters by one straight cut across the middle, and again cutting the two halves, keeping the cuts off any grid or other long straight lines. Thus four draftsmen may compile the remaining detail in ink, utilizing the control points and the main and secondary topographic lines as control.

(*g*) The four quarters are carefully rejoined with strips of cellulose tape or film base patches. The grid must be rechecked and made to meet every possible test. The main topographic lines are inked, together with the grid and geographic lines. From a previously prepared lettering diagram, guide lines are drawn, and the lettering inked (par. 94*d*). The editing, which has been underway since the work commenced, is now finished and the compilation of the map body is sent to the reproduction section.

(*h*) Several of the first proofs should be sent to the drafting section for a final check before the run of the press is started.

(*i*) The provisional map with form lines added as described in paragraph 36*g* is a later edition. The elevations of the ground control points will probably be known. Some trigonometric elevations in inaccessible (enemy) territory may have been obtained before this stage is reached. Perhaps enough elevations may be known for the method of 36*e*, but the marginal data must be changed to show "form lines with ---- ft. approximate vertical interval." No delay should be permitted for additional data. The stereoscopic form lines on the photographs should be expedited by using all the men available, and the compilation of these form line sketches commenced as soon as the plate for the planimetric edition is finished. As an edition with contours may be ordered later, the form lines are compiled on a separate sheet of film base, which is cut to the size of the tracing of the map body and secured thereto. The work of compilation will be speeded if a draftsman, other than the compiler, adjusts the ends of the form lines on the photographs (par. 87*a*(3)).

(*j*) The roughly contoured provisional map is made by compiling stereo-sketches made on photographs with the stereo-comparagraph onto the original tracing of the map, the marginal border being changed accordingly. If the need of this edition is foreseen, the first press copy of the planimetric edition should be marked with half-inch circles in the vicinity of each of the eight known elevations desired for each overlap, except where elevations are known, and

sent to the topographic unit with a request for such multiplex elevations as they are able to furnish without delay. Perhaps sufficient elevations may be obtained from the field if the multiplex elevations cannot be promptly supplied. In the meanwhile, additional copies of photographic prints will have to be secured, one to replace any on which form lines may have been drawn, and one left-hand photograph of each overlap which is to be contoured with the stereo-comparagraph. The contour ends on adjacent stereo-sketches are adjusted, and all are compiled on the original provisional map tracing.

91. Battle maps.—*a.* The uncontoured battle map (fig. 177) is an advance edition of the contoured battle map showing all planimetric detail of the latter but no contours. Its horizontal control is identical with that of the contoured battle map. Carefully mounted nine-lens composites from the T-3A camera with numerous auxiliary control points yield a strong photographic extension and full correction for distortions of tilt, relief, and variable flight altitude.

b. The contoured battle map of 1:20,000 scale (fig. 178) is the ultimate step in the army program of progressive mapping. Some general information on the production and use of this type of map was given in 90*b*(4). The contours are drawn with stereo-comparagraphs, vertically controlled by numerous spot elevations obtained from the multiplex aero-projectors, or the contours may be drawn directly from the multiplex special model. The photographs are taken so that there is a 60-percent overlap of the B or center prints of the composites. The vertical control is carried forward from known elevations into inaccessible territory by the multiplex with diapositives from the B negatives only. Not all of the composites are printed as only about one-fourth of them are required for horizontal control. For contouring with the stereo-comparagraph, all of the B prints and both lateral wings, A and C, are required. The slowest progress is made during the bridging of vertical control in the multiplex, which can be advanced about 12 to 15 miles in a three-shift day, and the reading of the spot elevations for use on the A, B, and C prints. However, these methods have given satisfactory results when tested over very rough terrain. Forty miles beyond control the average elevation error was 25 to 50 feet and the horizontal errors averaged between 100 and 200 yards.

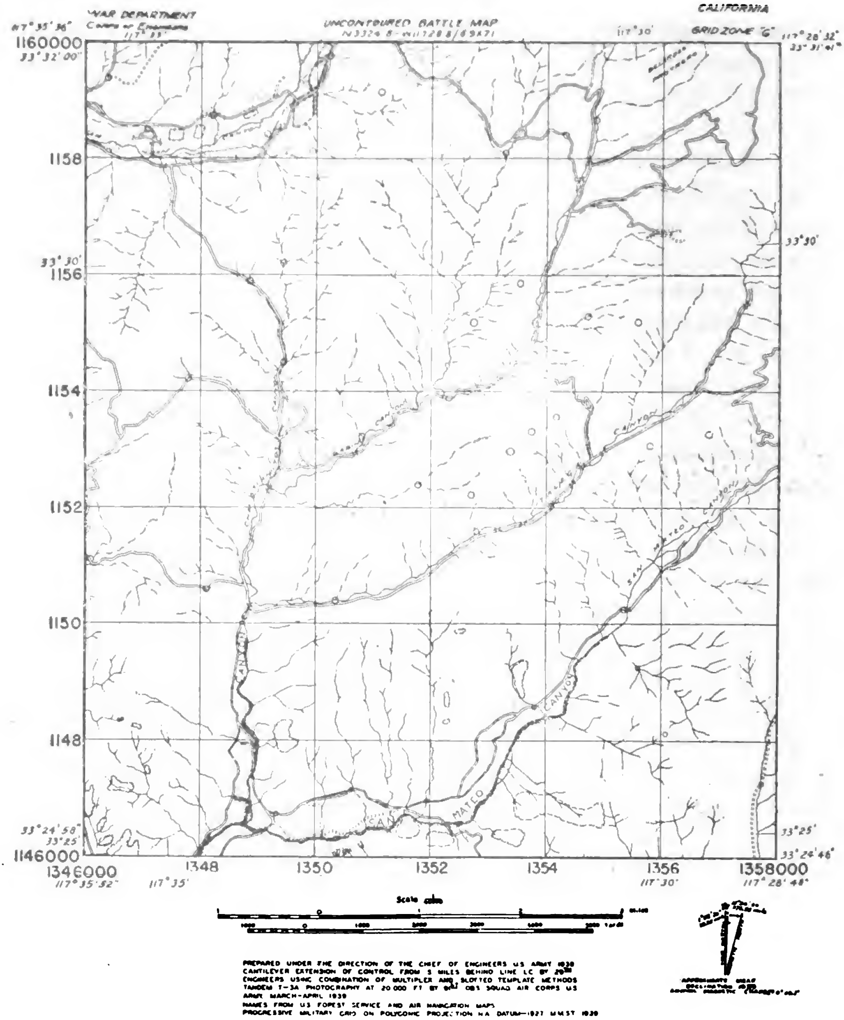


FIGURE 177.—Portion of 1 : 40,000 uncontoured battle map.

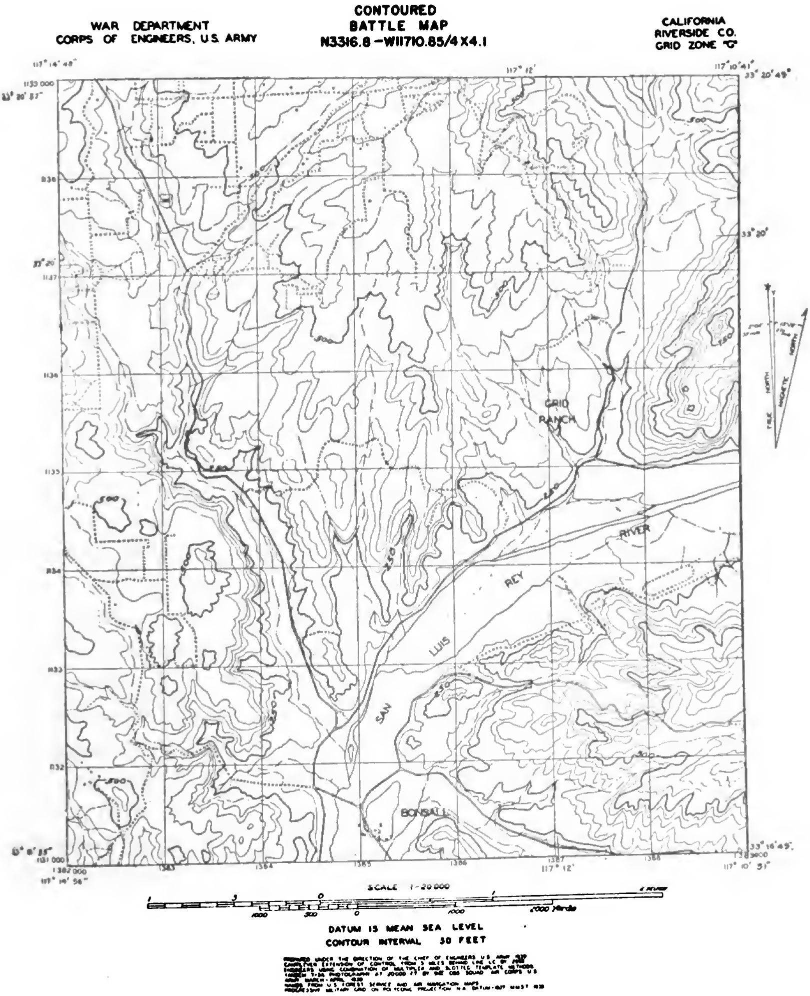


FIGURE 178.—Portion of 1 : 20,000 contoured battle map (exercise No. 31).

Section XX

COMPILING AND FINISHING MAPS

92. General.—*a.* Map compilation involves the making of a new map based on the following:

(1) Previous maps from any source whatsoever.

(2) Existing map data for any part of region covered by new map.

(3) Suitable aerial photographs of latest date available.

(4) Compilation tracings from aerial photographs especially made for new map.

(5) Supplementary information relating to topographic and special military features obtained by field parties.

b. Map compilation is distinctly office work and consists in the—

(1) Collection of available map data for new map.

(2) Selection of such data as found most suitable for the purpose.

(3) Reduction of selected map material to scale of compilation.

(4) Adjustment and plotting of selected data on compilation sheet.

(5) Inking and preparation of compilation sheet for reproduction.

93. Reduction to required scale.—*a.* If practicable, a compiled map should be drawn on a scale that is slightly larger than the scale of publication in order to derive certain advantages resulting from reduction. Before any map data, other than the initial control which is plotted to scale on the compilation sheet, can be transferred to the latter, such data must be reduced or enlarged to the scale of compilation, if necessary. The reduction is best effected by photography, or if suitable photographic equipment is lacking by the use of the pantograph.

b. Individual sketches or tracings, especially if made from aerial photographs, may be reduced to the scale of the compilation by the graphical method employing a grid of rectangular lines (squares). This is done as follows:

(1) Draw a grid on the original or on a piece of tracing cloth or paper if it is desired not to mark up the original. In this case the tracing cloth or paper should be permanently tacked over the original.

(2) On the sheet which is to contain the copy draw a similar series of squares bearing the desired scale ratio to the squares on the original.

(3) Transfer points on the original where the lines of the map intersect the lines of the grid to the corresponding points on the grid of the copy, using proportional dividers when practicable.

(4) Transfer necessary additional points by the coordinate method.

(5) Connect the points on the copy, referring constantly to the original to insure that similar figures and proportional distances are secured.

c. The details on the reduced copy are then transferred onto the compilation sheet. Figure 179 shows a sketch from aerial photographs reduced to scale.

94. Compiling and finishing.—*a. Preparation of compilation sheets.*—(1) Compilation sheets covering larger areas should be of best drawing paper mounted on metal (par. 11*a*) to avoid changes in scale due to atmospheric conditions. Smaller compilation sheets not exceeding, say 20 by 24 inches may be on double-mounted drawing paper or, if not available, on good drawing paper mounted on muslin. If equipment for indirect process photolithographic reproduction is not available, compilation sheets may be on topographic (nonshrinkable) film base or other transparent material suitable for direct process lithographic reproduction.

(2) The first step in the preparation of a compilation sheet is the construction of the grid for the area to be shown, and if necessary the corresponding meridians and parallels of latitude at the desired intervals. This is done according to the principles explained in paragraphs 68*d*, grid coordinates usually being constructed first and then, if necessary, the lines for geographic coordinates. If the borders of the map are meridians and parallels of latitude, the geographic coordinates are constructed first and the grid drawn to conform.

b. Control.—Before compiling any topographic data, all available triangulation stations and bench marks are plotted by the coordinate method on the compilation sheet. To the control points thus established all available data from other instrumental surveys are added in an effort to subdivide the sheet with lines of supplemental control into small sectors. The use of this additional data expedites the transfer of topographic detail later on.

c. Transferring and adjustment.—(1) Planimetric data of individual map sheets can be transferred best, if the compilation sheet is opaque, by direct tracing, using a pencil carbon sheet, preferably one made with a colored pencil, prepared by the draftsman. If transparent material such as photographic film base is used, each map sheet is fastened underneath the compilation sheet so that the corre-

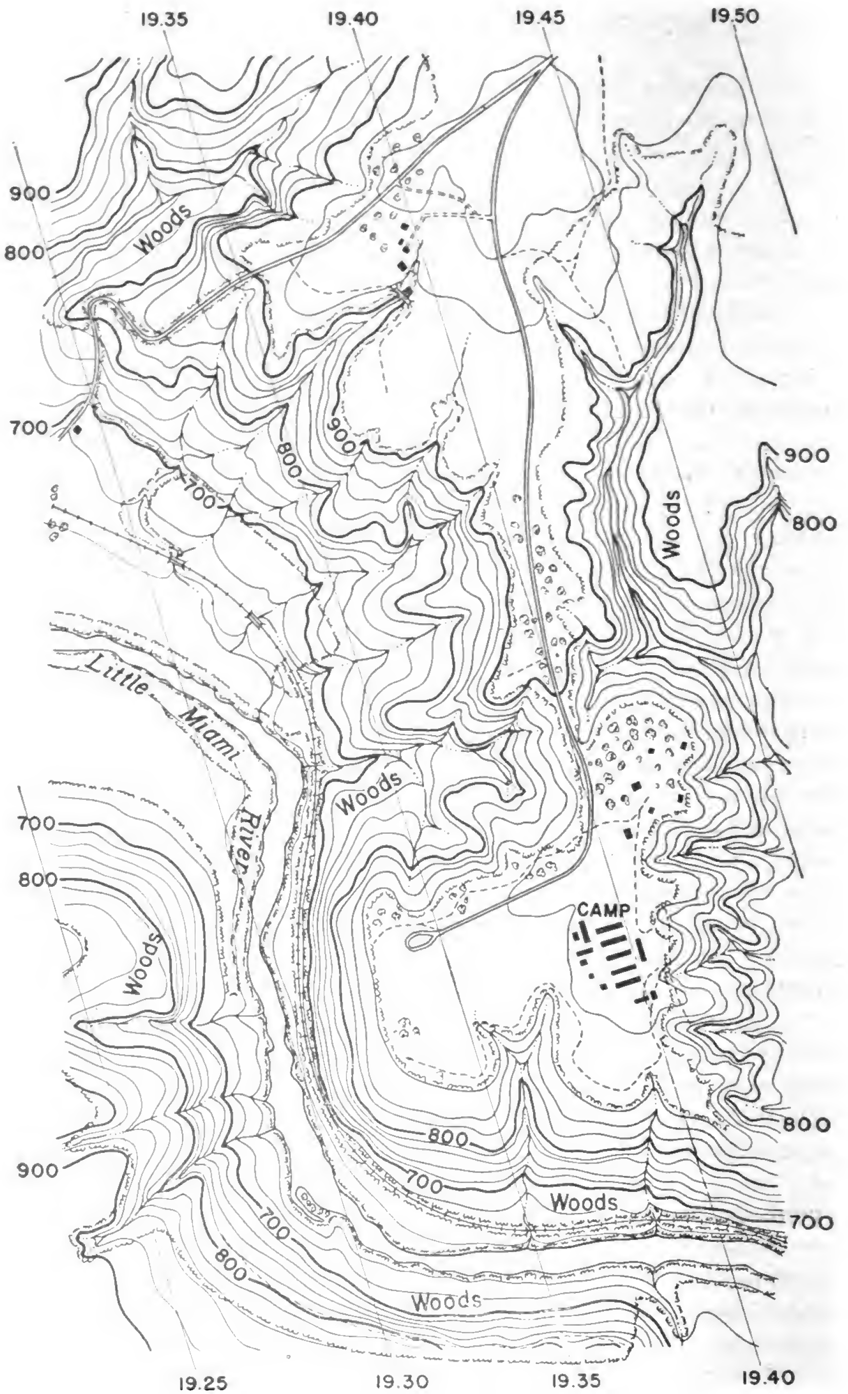


Figure 179.—Stereo-comparagraph sketch, with correction graph, from aerial photographs ready for compiling.

sponding control points and controlling features of both coincide. If they should not be in coincidence, as frequently will be the case, and the discrepancies are small, they may be distributed evenly between any two control points by tracing detail around one control point halfway to the surrounding control points and then shifting the compilation sheet in turn over each surrounding control point to extend the tracing.

(2) The most reliable maps or sketches, usually those with the most control, should be first incorporated in the compilation, as their plotting will often serve as an excellent guide and thus afford further control to which maps that have been less completely controlled can be tied.

(3) It is of course important that all topographic features, including man-made and natural, will be in perfect agreement along the borders of the individual maps or sketches. Slight differences which will not reduce the accuracy of the finished map are adjusted by the draftsman; maps showing differences that cannot be reconciled with the principle of allowable error plotting must be returned to the source where they originated for a check and correction.

d. Lettering.—(1) In planning the lettering for the map, especially larger maps, a complete diagram is made showing the position of all lettering. This diagram, made in pencil, can be a photograph or photo-lithograph of the compilation, or it can be made on tracing paper with the principal features, such as roads, railroads, etc., roughly traced thereon to facilitate orientation of the lettering later on.

(2) Lettering should be placed so the map is not congested with names, and in selecting places to be named consideration should be given to the relative importance the feature has to the whole map. Authorized abbreviations should be used wherever practicable. All place names should be lettered in a horizontal position. Lettering of features running true north and south and lettering of features slanting toward southwest and northeast should be placed to read from the southwest up, and lettering of features slanting toward northwest and southeast should be placed to read from the northwest down. Lettering must conform to paragraph 3*a*(3), FM 21-30, and may be done either by hand, by means of pasting type impressions on the map, or by a combination of both. (See AR 300-15 and par. 21*a*.) For smaller maps or maps that must be finished more quickly by single-stroke lettering see paragraph 20*b*. Such lettering is comparatively easy to do and reproduces well. All marginal data, shown in figure 88, paragraph 24*c*, and described in paragraph 48 must be added onto the map.

e. Inking.—The process of reproduction determines the character of the finished sheet and to a certain extent influences the method of inking. The usual process of reproduction in black or colors is by photo-lithography. If the map is to be published in black only (for color maps see par. 95), which is the general practice in the theater of war, all features, including the lettering and marginal data, to be shown on the map to be published are inked with lines, etc., of proper weight. (Lettering may be applied to the map as explained in *d* above; see also par. 24*a*.) All inked lines, no matter how fine, must be deep black and opaque for best results in reproduction. Here it should be remembered that the lithographed copies cannot be better than the original from which the copies are made. For drafting instructions regarding the reproduction of maps in colors see paragraphs 24*a* and 95.

f. Checking and editing.—(1) In smaller units the checking and editing of the inked map (compilation sheet) are usually done by one person. In larger units, such as topographical battalions, these duties may be divided between several men.

(2) The need for an immediate checking of the inked map by a person other than the inker arises from the expectation that one who has worked on a map for days and perhaps weeks may, through inadvertence, misinterpret or omit some essential data or make errors. If more than one person works on a map or on adjoining maps, a checking is needed to reconcile possible differences that may be found.

(3) It is the duty of the checker to examine the inked drawing and its field material, through all its features and from every point of view that can suggest itself to an experienced topographer, and as a result of this checking to call attention of the inker to all details that need correcting.

(4) The checker should inspect the inked sheet, paying particular attention to the quality of drafting, especially for congested places; completeness of copy, both within the margin and outside; uniformity in the expression or treatment of detail by comparison with maps of surrounding areas; appropriate location of bench marks and useful elevation figures in their relation to adjacent contours; and uniform use of standard symbols within the map itself and those used on maps of surrounding areas.

(5) After the map is checked, inspected, and corrected it must be edited. The list given below will be found suggestive of detail that should receive consideration and attention by the map editor before it is transmitted for reproduction. The map editing should

include, among other items: military grid; projection; scale and contour interval; marginal lettering and scales; adjoining borders; flying fields, etc.; post offices; railroads and stations; names of localities; boundaries of governmental subdivisions; national forests, parks, and monuments; Government reservations (Federal, State, etc.); power transmission lines; waterlining and tints; depression contours; punctuation; position of lettering; abbreviations; position of control stations and bench marks with their elevations; style of lettering, etc.

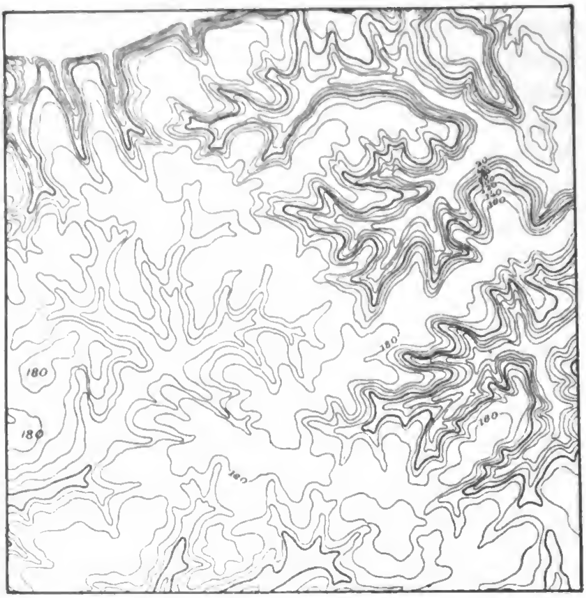
g. Overlays and overprints.—Data for overlays and overprints (par. 43*c*(2) and (3)) receive the same treatment in compilation, etc., as described above for maps. The detail shown on overlays and overprints, usually collected and correlated by and under the direction of the staff, is generally much easier to draw than that for a base map, but because of special importance of the data shown and the utmost speed with which these overlays and overprints generally must be completed, the best men only should be entrusted with their execution. Those engaged in this work should be thoroughly familiar with the special symbols and abbreviations given in FM 21-30.

h. Rapid compilation.—To shorten the time of compilation, topographic film base or some other suitable transparent material may be used for the compilation sheet. This permits the direct transfer, by tracing, of detail from field and office sketches or photographs onto the compilation sheet, observing of course, as far as time and circumstances permit, all directions for compilation and finishing described in paragraph 89 and in *a* to *f*, inclusive, above.

i. Exercise No. 32: compilation of a map.—(1) On a partly completed control sheet similar to one constructed in exercise No. 25, which must cover the area indicated on stereo-comparagraph drawings (stereo-sketches), contoured photographs, sketches, etc. (to be furnished the student), plot all available supplementary (photograph) control and, if required, any other control that may assist in the compilation.

(2) Adjust along the boundaries between the different drawings or sketches, etc., all topographic features and detail so that they are in perfect agreement and trace them in ink to form a complete map. Finish the sheet as described above and as shown in figure 180.

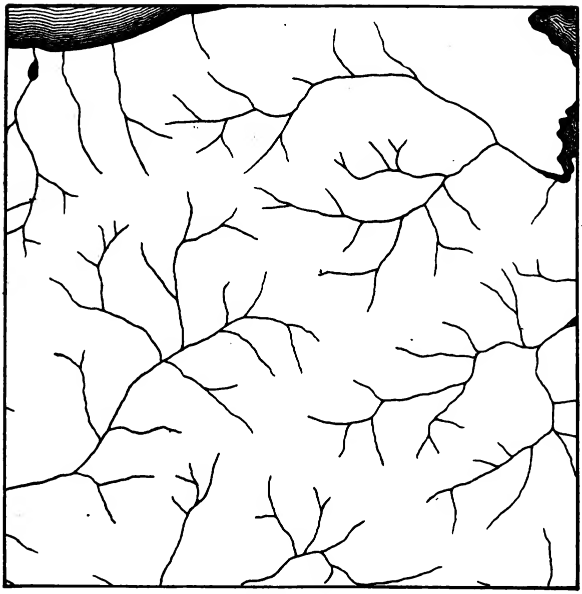
95. Drawings for color maps.—If the map is to be printed in more than one color, a separate drawing for each color used is made (par 24*a*). The most satisfactory method of doing this is on light-blue photographic copies, on metal-mounted paper, sensitized for



(For brown.)

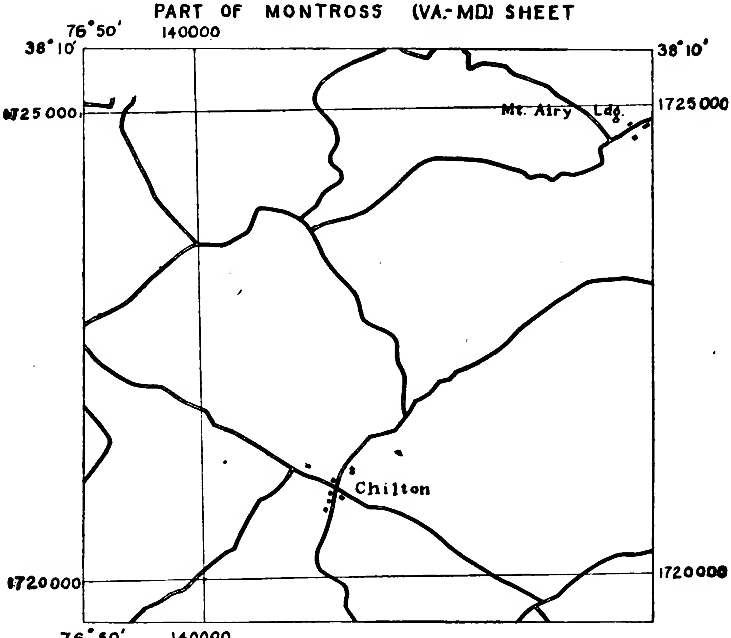
(For green.)

FIGURE 181.—Drawings for four-color map.



(For blue.)

PART OF MONTROSS (VA.-MD.) SHEET



Scale 1:62500

1 ½ 0 1 2 miles

Contour interval 20 feet.
Datum is mean sea level.

(For black.)

FIGURE 181.—Drawings for four-color map—Continued.

that purpose, or on photo-lithographic copies of the pencil compilation, printed in nonphotographic light blue on bristol board. Only the features that are to be printed in the same color are included in one drawing, and as the blue copies are identical, perfect registration can be obtained when the reproductions of the several drawings are combined in the printed map (fig. 181).

Section XXI

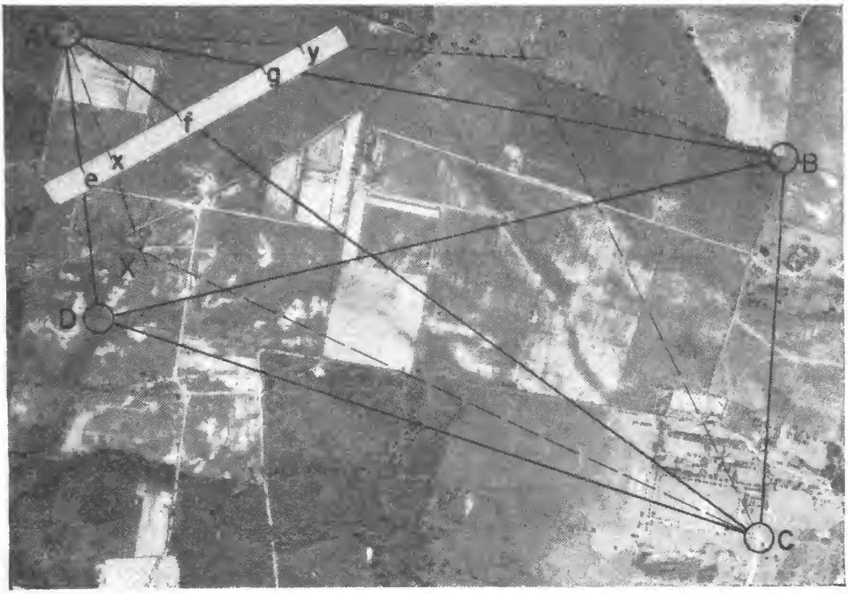
RESTITUTION

96. General.—*a. Definition.*—Restitution is the graphical determination of the true (map) position of objects or points the images of which appear distorted or displaced on aerial photographs.

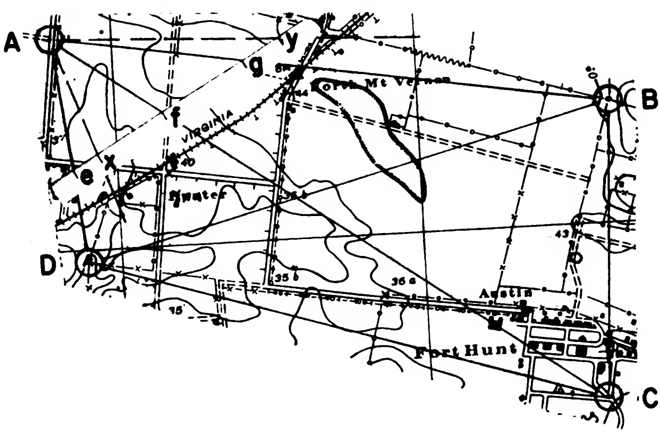
b. Purpose.—It should be realized at this stage that vertical photographs cannot be accurate maps in fact unless a variety of impossible or impracticable conditions is satisfied. These conditions would include perfectly level terrain, a perfectly level stationary camera platform, mechanically perfect camera, and perfect camera lens, film, print paper, and weather. It has been shown that good vertical photographs of terrain of small relief approximate the characteristics of a map. However, it is desirable that the draftsman be able to use, either in conjunction with maps or as substitutes for maps, photographs which contain tilt or obliquity and relief. He should be able to plot the map positions of images recorded on such photographs and know how to transform the detail from the oblique to the horizontal when desired for correcting existing maps or in the construction of new ones. Some practical methods of restitution are described in the following paragraphs. Most methods described restore the incorrect position of points to their correct or nearly correct photographic position, correcting for displacements of tilt only. The radial line method (par. 97*c*) is the only method which makes corrections of displacements due to both tilt and the relief of the ground.

97. Graphical restitution methods.—*a. Location of points by strip method.*—This method may be used to determine the map location of a few points on an aerial photograph. It may be employed with both tilted and oblique photographs. It will not eliminate the effect of displacements of position caused by relief. It is especially useful in bringing maps up to date by locating on the maps features which did not exist at the time the map was made. It is not necessary that

the map and photograph be of the same scale. Assume that it is desired to determine the map location of Y and X, respectively, on an aerial photograph. (See fig. 182.)



① Photograph.



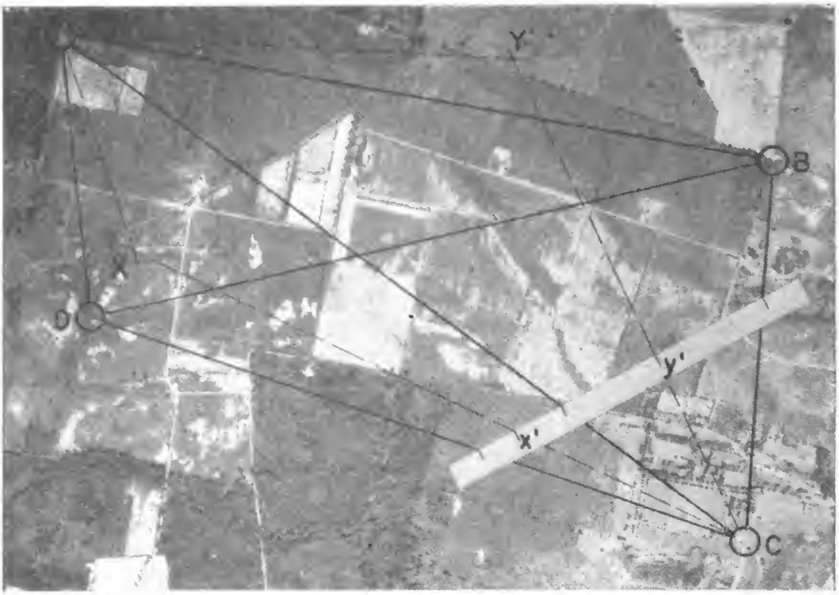
② Map.

FIGURE 182.—Paper strip method of restitution.

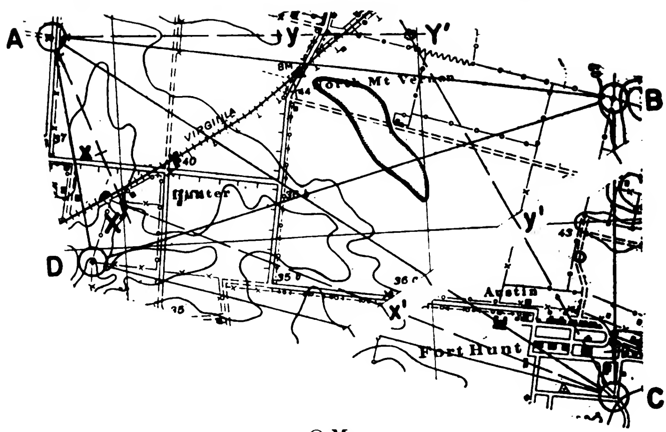
(1) Select as control four points readily identifiable on both the photo and the map (A, B, C, D) and join them by lines as shown. In

general, the points, the locations of which are desired, should be within or near this quadrilateral.

(2) Draw the diagonals AC and BD.



③ Photograph.



④ Map.

FIGURE 182.—Paper strip method of restitution—Continued.

(3) From any two of the four control points on the photograph, as A and C, draw rays through the points X and Y. Select the ray centers to give good intersections at the desired points.

(4) Place a paper strip as in figure 182 ① and mark on the paper strip *e*, *f*, and *g* (points where the lines of the figure cross the strip) and *x* and *y* where the rays to *X* and *Y*, respectively, cross it.

(5) Place the paper strip as in figure 182 ② so that *e*, *f*, and *g* fall on their respective lines from *A*, and mark on the map the points *x* and *y* as determined by the marks on the paper strip.

(6) Draw rays on the map from *A* through *X* and *Y*.

(7) Similarly place another strip or the reverse side of the paper over the photograph as in figure 182 ③ marking the position of the five rays from *C*.

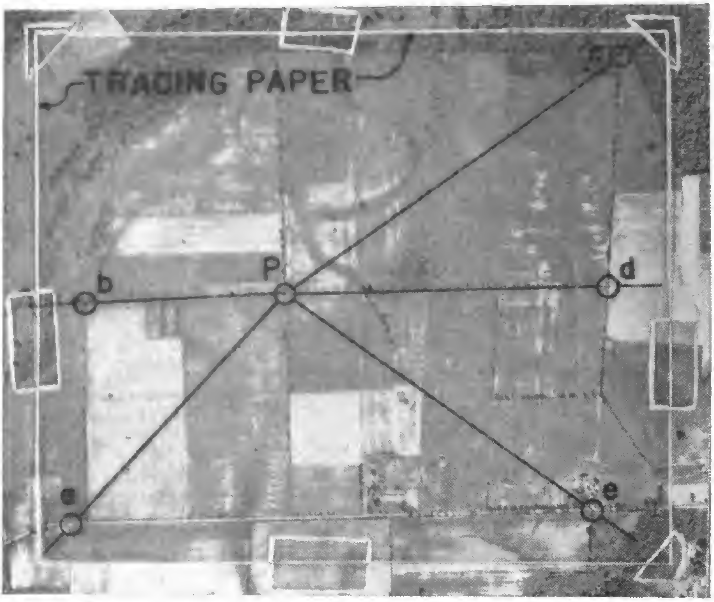
(8) Place this second strip on the map as in figure 182 ④, mark on the map the points x' and y', and draw the rays Cx' and Cy'. The intersections X' and Y' give the locations on the map of the points *X* and *Y* on the photograph.

b. Location of a point by tracing paper method of resection.—(1) The method of resection by means of a piece of tracing paper may be used to plot roughly the map position of a limited number of points appearing on a vertical photograph.

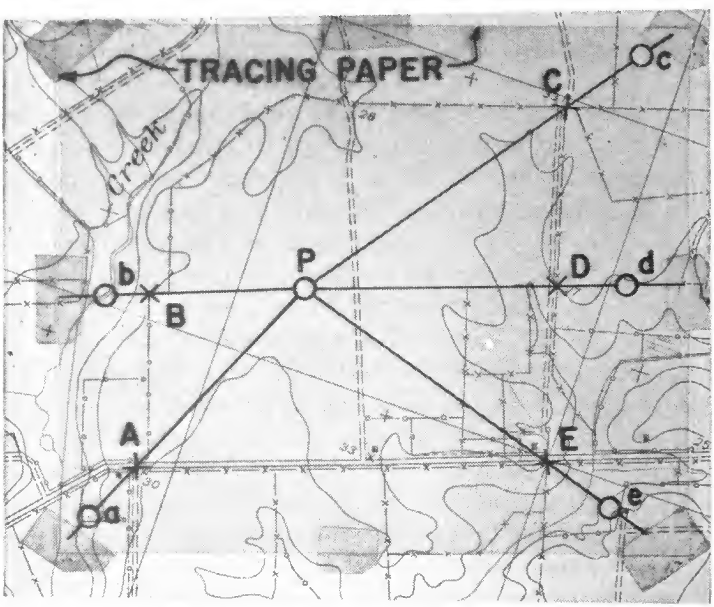
(2) Identify on the photo at least three points (preferably five) that appear on the map. (See fig. 183.) Mark on a sheet of tracing paper the position of these points and of the point to be located on the map. This is done most readily by tacking the photograph over the tracing paper and with a pin pricking through each point. On the tracing paper draw rays from the point *P*, the location of which is desired, to each of the known points as *a*, *b*, *c*, *d*, and *e*. Place the tracing paper on the map so that the ray to each of the known points passes through the map location of the corresponding point. The point, the location of which is desired, is then in its relative position to the known points. Its position may be pricked onto the map.

(3) This method cannot be properly termed restitution because errors of tilt and relief in the photograph are in no way corrected unless the point, the location of which is desired, chances to fall, in their respective cases, either on the isocenter or the plumb point of the photograph. However, the error of location can sometimes be reduced by selecting more than the minimum of three known points. Thus five known points may be selected, and it may not be possible to cause all five rays to pass through the respective map positions at one time. If four rays can be made to do so, the other ray may be deemed in error and disregarded.

c. Location of a point by radial line method.—For practical purposes the combined effect of relief and tilt in slightly tilted photographs is assumed to cause displacements along a radial line passing



① Photograph.



② Map.

FIGURE 183.—Location of point on map by tracing paper method of resection.

through the principal point (center) of the photograph (par. 78*b*). Use is made of this assumption to provide a method for determining accurately the map position of a point appearing in the overlap of two aerial photographs taken at different camera positions. This method of restitution is the only one which will correct for both relief and tilt. When the tilt is small (3° or less), the assumption that displacements are radial along a line passing through the principal point is within the bounds of plotting accuracy. The method fails, however, in the presence of excessive tilt and cannot be used with oblique photographs. It is not necessary that the two photographs used are of the same scale. However, if the point sought falls on or near the line joining the centers of the two photographs, the method fails because of the lack of a good angle of intersection. Assumed that it is desired to locate on a map an object A (fig. 184) which appears on two overlapping vertical photographs. Proceed as follows:

(1) Identify on the map and on each of the two photographs three points which will serve to orient the photograph with respect to the map. A different set of points may be selected for each photograph or the same identical points as X, Y, and Z shown in figure 184 ① . The points selected should be well out from the center of each photograph and so distributed that the rays drawn from them to the center of each photograph provide good three-ray resection. Points grouped too closely cause acute intersection angles between the rays drawn to the center of the photograph and make accurate work difficult.

(2) Enclose the three points selected on the photograph and the map in small triangles. Enclose the object A to be located on the map in a small circle on each photograph.

(3) Place a piece of vellum over the map and mark on the vellum the map positions of the points X, Y, and Z (fig. 184 ①).

(4) Locate on each photograph (marked Nos. 1 and 2) the principal point (center) and mark this with a cross, C_1 and C_2, respectively. Draw rays from the photograph positions of X, marked X_1 and X_2, respectively, Y, Z, and A to C_1 and C_2, respectively (fig. 184 ② and ③).

(5) Place the vellum over photograph No. 1 and orient it so that the points X, Y, and Z marked on the vellum will fall on the rays drawn on the photograph through the images of those points (X_1 Y_1 and Z_1). Trace on the vellum the ray drawn through the object A_1 (fig. 184 ④).

NOTE.—In doing this we have in effect located on the vellum by resection the position of A with respect to C_1. Any displacement of A_1 due to relief or tile is radial along this line.

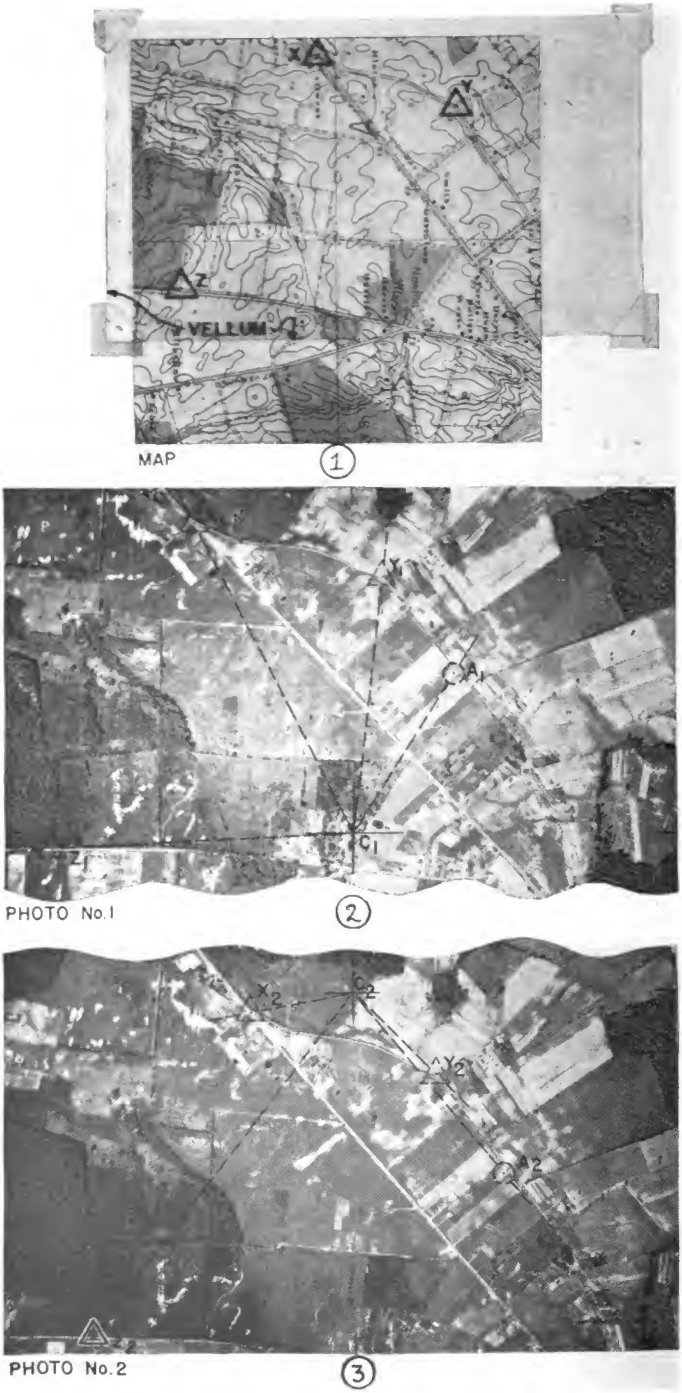


FIGURE 184.—Radial line method of restitution (exercise No. 33).

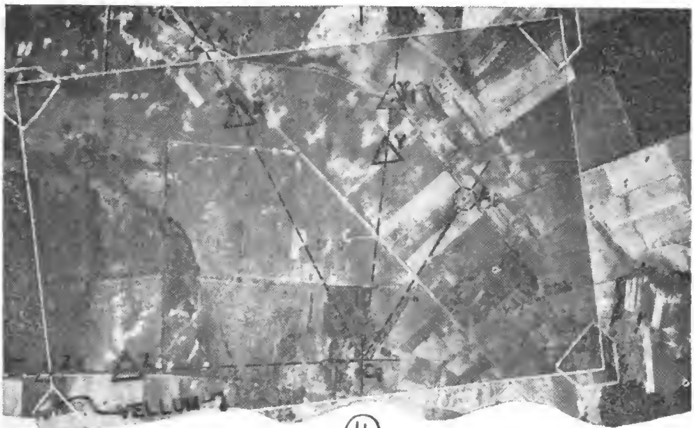


PHOTO No. 1 (4)

PHOTO No. 2 (5)

MAP (6)

Figure 184.—Radial line method of restitution (exercise No. 33)—Continued.

(6) Next place the vellum over the photograph No. 2 and orient it so that the points X, Y, and Z marked on the vellum again will fall on the rays drawn on the photograph through the images of those points X_2, Y_2, and Z_2. Trace on the vellum the ray drawn through the object A_2 (fig. 184⑤).

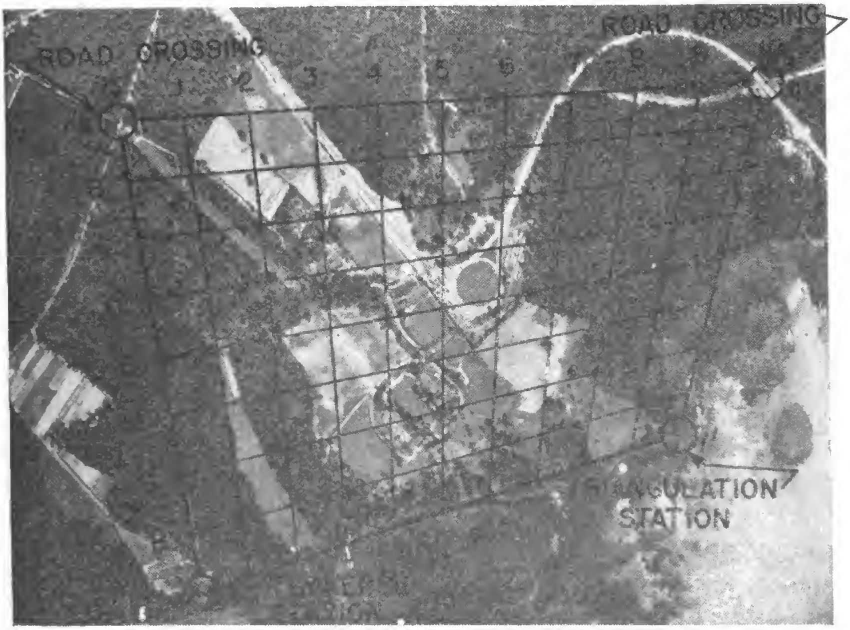
(7) The intersection of the two rays through the objects A_1 and A_2, respectively, as traced on the vellum, plots the position of A to the scale of the map. The vellum may again be placed over the map and oriented so that the positions of points X, Y, and Z on the vellum and on the map are superimposed one above the other (fig. 184⑥). The position of A may then be pricked onto the map.

d. Rectification of areas by grid method.—(1) The grid method of enlarging, reducing, or reproducing an aerial photograph or map is similar to the one described in paragraph 93*b*. Homologous grids (fig. 185) are employed as an expedient to rectify slightly tilted photographs. This method is not applicable to oblique photographs nor will it eliminate the effect of displacements of position caused by relief.

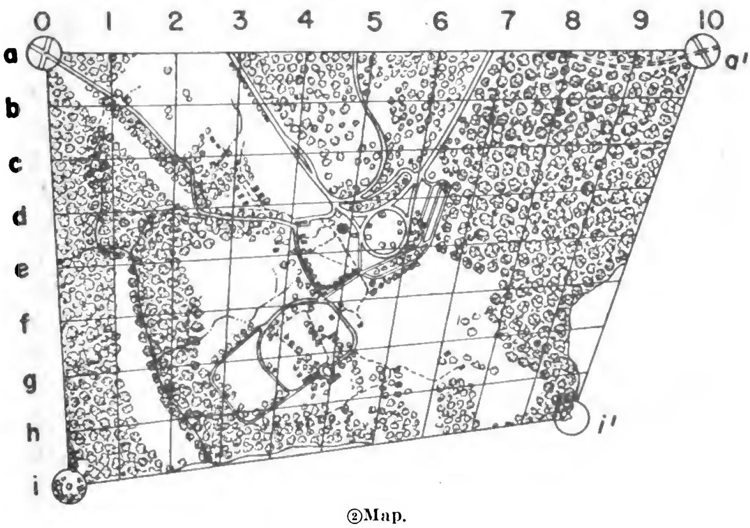
(2) In order to rectify a photograph, select four well-distributed points such as A, A', I, and I' in figure 185① about the margin of the photograph which can be identified on a map. Crossroads, road junctions, important buildings, bridges, or other well-defined locations are suitable. Join the four points on both the photograph and the map by straight lines to form a four-sided homologous figure on each. Divide the opposite sides of the two figures into the same number of equal parts from ½ to 1 inch in length. Joining the divisions laid off, draw on both the photograph and on the map grids which serve to subdivide the respective areas into the same number of small homologous figures. Finally, copy in homologous relation the detail appearing in each grid subdivision of the photograph in the corresponding subdivision of the map (fig. 185②).

e. Rectification of areas by triangular division method.—(1) *General.*—This method may be used to rectify either a tilted or an oblique photograph. It is based upon the theory that straight lines on the map appear as straight lines on the photograph. It will not eliminate the effect of displacements of position caused by relief.

(2) *When only four control points are available.*—Select four points, such as A, B, C, and D in figure 186, on the photograph which can be identified on the map and so distributed as to include the area under consideration. Join these points with straight lines to form a four-sided figure such that the opposite sides, when extended, will meet in points F and G at a convenient distance. If these points fall

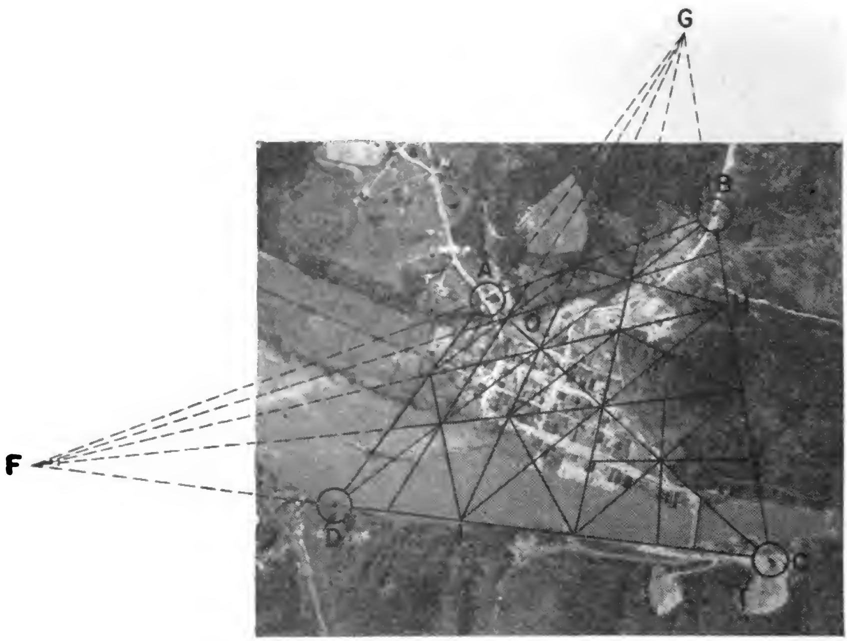


①Photograph.

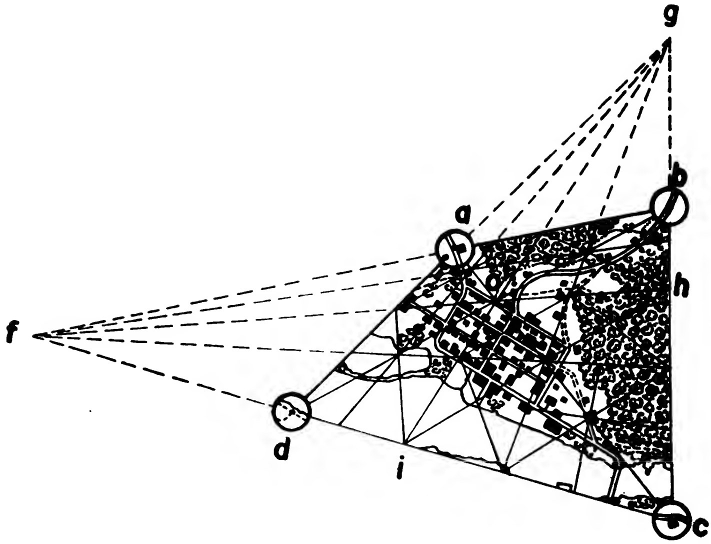


②Map.

FIGURE 185.—Grid method of restitution.



① Photograph.



② Map.

FIGURE 186.—Triangular division method of restitution with four control points.

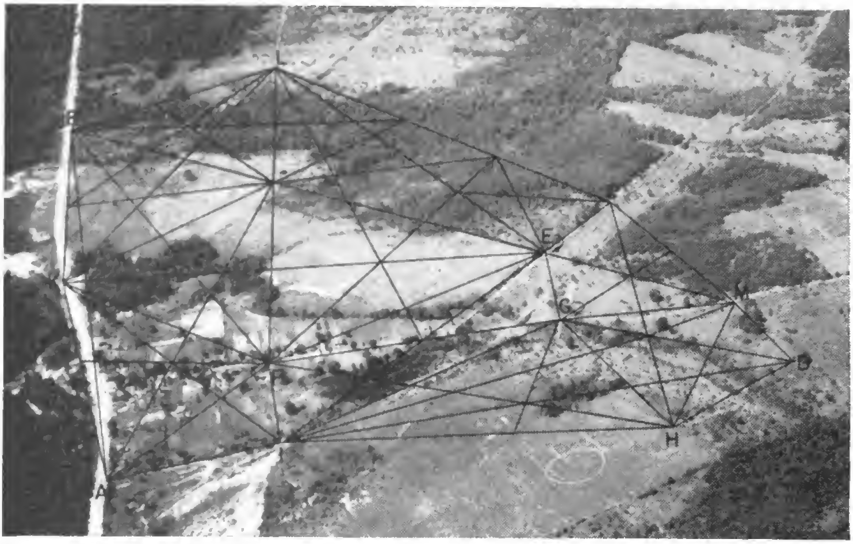
off the photograph, either they must be extended onto another piece of paper or an overlay of a large sheet of tracing paper must be used. Draw the diagonals *AC* and *BD*. Through their intersection *O* draw lines *FH* and *GI* from *F* and *G*, respectively. It may be observed that in addition to the four control points originally selected, there are now five more points, *F*, *G*, *H*, *I*, and *O*, the positions of which are fixed. The figure *ABCD* has been subdivided into four smaller four-sided figures. Draw diagonals in each of these and continue the process until the "controlled" subdivision of the area results in triangles of suitable size, usually about ½-inch sides. Using the corresponding points *a*, *b*, *c*, and *d* on the map or on an overlay traced from the map, proceed similarly to produce the same number of homologous triangles. Finally, copy in the triangles of the map figure the corresponding detail as it appears in homologous relation in the corresponding triangles of the photograph figure.

(3) *When more than four points of control are available.*—When more than four points of control are available the method is simpler and can be done in less space. On an overlay, trace from the map a large number of well-distributed control points, such as *a*, *b*, *c*, *d*, *e*, etc., in figure 187, which can be identified readily on the photograph. Proceed to join by lines these points as they appear on the map and the photographs, respectively, producing homologous figures. Using diagonals as necessary, carry the subdivisions further to produce triangles small enough for the desired accuracy without causing undue congestion. Proceed to copy the detail from the photograph triangles to the corresponding map triangles. Figure 187 illustrates the mechanics of the method in its application to the rectification of an oblique photograph.

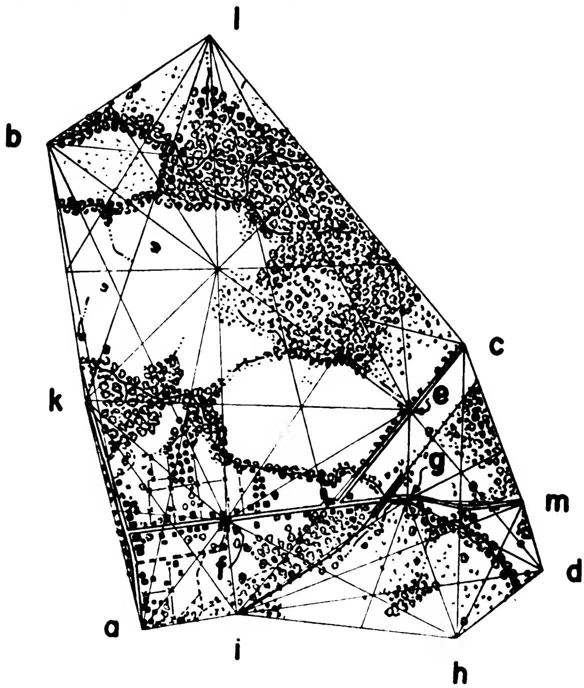
f. Other graphical methods.—There have been and are in use other graphical methods, such as the pyramidal method, which require elaborate constructions by descriptive geometry. Because of their impractical nature they are not included here.

g. Exercise No. 33: radial line method of restitution.—Locate a point *M*, marked on a photograph, on an incomplete map using the radial line method, as explained in *c* above (fig. 184).

98. Restitution by photographic methods.—Restitutions made photographically are, if available, the most satisfactory of all the various types. They give a rectified (horizontalized) photograph which can be used in connection with other overlapping rectified photographs to plot points with great accuracy. The method requires that all photographs embrace four points of control, and it is necessary to know the relative elevations of the control points in order to



① Oblique photograph.



② Map.

Figure 187.—Triangular division method of restitution where more than four control points are available.

work with accuracy. However, manipulation of the copying (transforming) camera is complicated and requires considerable skill. The principles of this method are employed in transforming the oblique photographs of the multiple-lens camera to the plane of the center negative to make composite vertical photographs. This method does not correct for the effect of relief.

SECTION XXII

MOSAICS

99. Definition.—It has been shown that the greater the altitude at which the photograph is taken the greater will be the size of the ground area included in the photograph. However, there is a limit to the altitude from which suitable and satisfactory photographs can be taken and it is often impossible to include in a single exposure the total ground area desired. Resort is then made to the taking of a number of vertical photographs in such a way that they can be joined to form a single picture. As the combining of the individual photographs resembles the art of joining pieces of colored glass, stone, tile, etc., in the form of decorations or pictures called mosaics, the term "aerial photographic mosaic" has been applied to a group of overlapping vertical aerial photographs assembled to form a single picture.

100. Value.—The taking of vertical aerial photographs and their assembly into mosaic form are most important functions of observation units of the Air Corps. However, the engineers have made and probably will continue to make mosaics, especially controlled mosaics, and it is for this reason that instructions for making controlled mosaics by the most advanced methods are included in this manual. For strip mosaics and uncontrolled mosaics see paragraphs 41 and 42. Controlled mosaics are valuable for a variety of military purposes only when topographical maps are not available. They can be produced under war conditions in a surprisingly short space of time and with a fair degree of accuracy, and since every object on the ground is reproduced in the photograph in its proportional plan view size, and information of elevations may be secured through a stereoscopic study of separate overlapping pictures, mosaics compare favorably for miltary purposes with other hasty maps.

101. Controlled mosaics.—*a. General.*—The steps in sequence embraced in the production of a controlled mosaic from the time the photographs are received are as follows:

(1) Selection of uniform scale for assembly.
(2) Preparation of mount.
(3) Preparation of photographic prints.
(4) Control plot by radial line method, or
(5) Control by templet method.
(6) Adjustment of prints.
(7) Assembly procedure.
(8) Grid system and data.
(9) Finishing mosaic.
(10) Reproduction of mosaic.

The photographic prints are laid out and their numbers checked against an index map usually a duplicate of the flight map. The index map is useful for a number of purposes during the production of a mosaic. In the first place, the plottings on the map show whether the area photographed has been fully and properly covered. During the assembly of the prints in mosaic form, the map will prove a valuable aid in the selection of the individual prints to cover any desired portion on the mounting sheet. Also, after the assembly of the mosaic has been completed, the index map serves as a reference for quickly obtaining negatives covering any particular area, reproductions of which may be desired for close study. This is of particular value in wartime.

b. Selection of uniform scale for assembly.—With increasing demand for accuracy as well as the increase in the size of mosaics, it is necessary to determine first a common scale of the photographs used. This, of course, need not be done if the negatives from which the prints are made have been reduced to a uniform, common scale. The scale selected may be either the mean scale of the first two photographs or the mean or average scale of the photographs to be included in the mosaic. (See par. 78*e* and *h*.)

c. Preparation of mount.—A mounting sheet of suitable composition board, on which the photographs are to be mounted later, is next prepared. On this sheet are plotted all ground control stations which can be identified on the photographs. This sheet is prepared as explained in paragraph 68 with the military grid lines extending slightly beyond the edges of the mosaic.

d. Preparation of photographic prints.—The photographs to be used are marked with all ground control points that previously have been plotted on the mount. But since aerial photographs seldom

show the correct positions of these instrumental control stations due to variances in scale resulting from relief, tilt, and variable altitude, etc., supplementary control data must be obtained in order to reconcile such errors. To do this the radial line method or one of the templet methods (par. 78 or 79) is used. Additional control points, as explained for the radial line method are selected and marked on the photographs.

e. Control plot.—With the ground control points plotted as stated in *c* above, the additional (photographic control) points are then plotted and adjusted (par. 78), or if equipment is available to employ the templet method (par. 79), a templet of each photograph is prepared and the supplemental control adjusted and plotted.

f. Assembly procedure.—(1) *General.*—By the term "assembly" is meant the actual pasting of the photographs in position on the mount. When all the prints have been pinned down in their proper positions on the mount, the assembly is ready to begin. The point where the actual assembly begins is immaterial as any errors in matching will be dropped as they occur, and each print is placed on its control regardless of slight errors in matching adjoining prints. It must be remembered that no matter how perfect the matching of the prints, if there are differences in elevation in the terrain covered by a picture, small inaccuracies in scale, inherent in the picture, will be found in the mosaic, as it is impossible in many cases to join continuous detail, common to adjacent prints, perfectly. If the assemblyman insists on exactly matching each print, the slight errors, immaterial in themselves, may accumulate to a point where he must either ignore his control net or make one large, very apparent, and material error. Final accuracy must not be sacrificed for temporary appearance. The control points must be utilized to their full extent. The set of prints which have been pinned to the mount are not used for assembly but are replaced one by one as the duplicate print is pasted in place. The position and orientation of each print pasted down are determined by its relative position to the surrounding prints. When a print is thus adjusted it is permitted to stick fast to the mount, it being known that this is the best adjustment that can be obtained. Exceptional care should be taken that the pin-point location of each instrument control station is in its exact location before the print is permitted to stick immovably to the mount.

(2) *To trim prints.*—Before applying the adhesive, the print should be trimmed to the desired size. The trimming of the edges of a print which will overlap those of an adjoining print is a very delicate and painstaking feature of mosaic assembly. In deciding where to cut a

print, consideration should be given to blending print tones and also to the availability of natural breaks in the terrain, such as ditches or edges of fields and woods, as these afford excellent concealment for the joints. It is best to avoid cutting a print at or near the edge of a road, as it might be widened noticeably by the slight contraction of the print when dry. Upon skill and ingenuity in this respect depends a great portion of the finished appearance of the mosaic. Trimming is accomplished by feather-edging or beveling the overlapping print along selected lines. If the edge of the selected line of junction is through wooded area, the print should be held between the thumb and forefinger of both hands so that the emulsion is toward the operator and the left hand twisted away from and the right hand toward him, thus producing an uneven or ragged tear which is barely perceptible when the print is mounted. If the junction is to be along a straight line, the tearing will be facilitated by first cutting the surface of the print along the desired bevel and exerting only sufficient pressure to penetrate the emulsion. After the print is torn it is good practice to scrape the edge with a razor blade or rub it with fine sandpaper to remove any roughness.

(3) *Adhesive used.*—The adhesive generally used for mosaic assembly is a mucilage made from gum arabic. The advantage in using this is that after it is applied the print may be placed in its approximate position and then moved slightly in any direction for adjustment to its precise position. The principal disadvantage is that owing to its water content it causes the print to expand, and allowance must therefore be made in the adjustment of the dry prints for the amount which they will probably expand when the adhesive is applied. Any adhesive which may be forced from under the surface of one print onto another may readily be removed by means of a tuft of cotton dampened with water. The edges of the prints should be pressed down and rubbed until entirely dry to prevent subsequent curling. Staples, rubber cement, various pastes, and cellulose tape also have been found useful as temporary or permanent adhesives.

(4) *To join sections.*—If the mosaic is too large to be made in one section and the assembly has progressed to the edge of a section, the adjoining section should be placed in position and the assembly continued as if no division of sections existed. When the prints which are pasted over the joint are dry, the sections are again separated by cutting with a razor blade at the line of junction of the sections. This will insure perfect matching of the various sections of the mosaic.

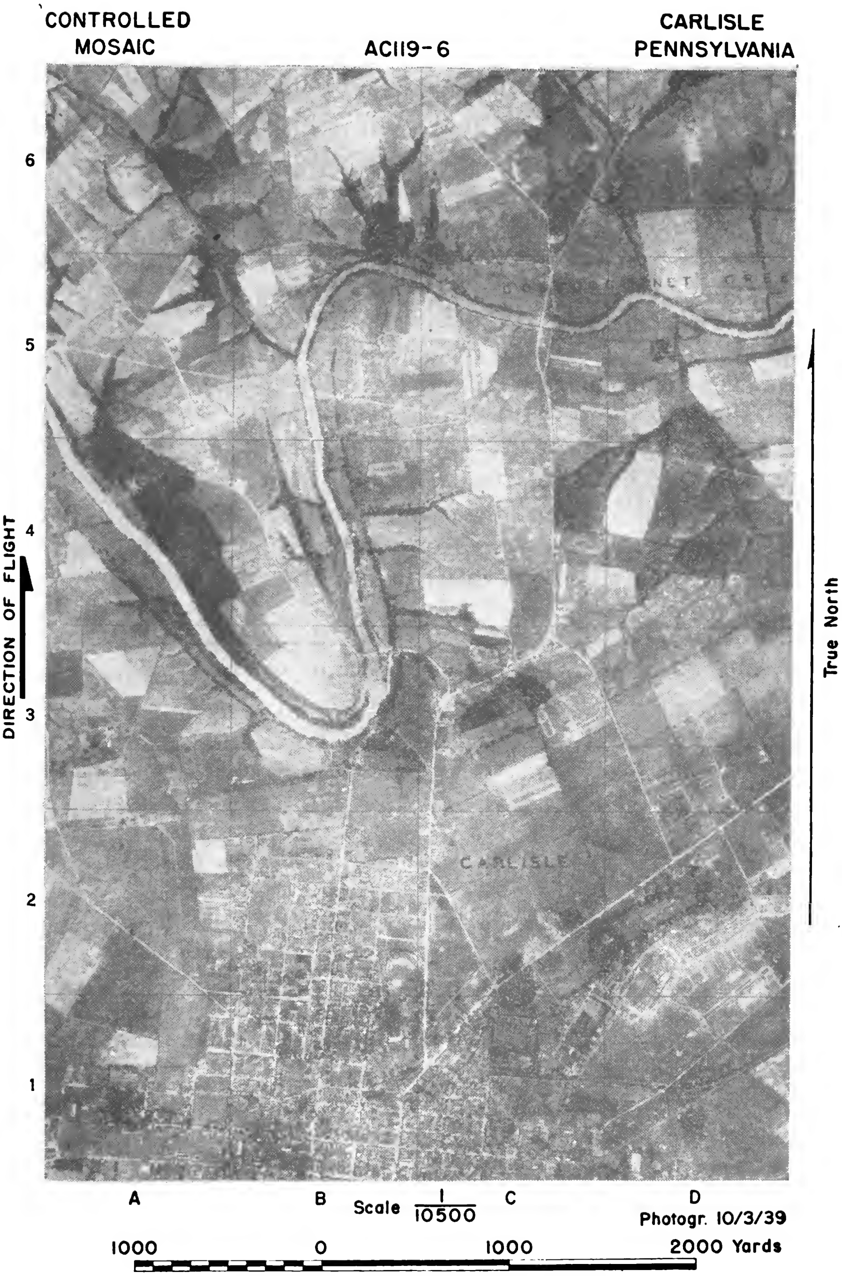


FIGURE 188.—Copy of completed mosaic.

(5) *Completion of assembly.*—When the extreme boundaries of the mosaic are reached, care should be taken that the ends of the grid lines on the mount are not covered as these lines will be used later in the projection of the grid onto the mosaic. Avoid irregular borders, always trying to have them rectangular and parallel to the grid lines. It will be found that a surprising amount of dust and dirt has accumulated on the surface of the prints during the assembly. This may be removed by gently wiping over the surface of the prints with a piece of absorbent cotton slightly dampened with water. No injury to the mosaic will result if care is taken to wipe away from and not toward the edges of the overlapping prints. The use of alcohol for this purpose is not recommended as it has been found to neutralize the adhesive where it penetrates the paper, thus causing subsequent peeling and curling of the prints.

g. Grid system and data.—After the mosaic has "set," the grid system is projected onto same to conform to the ends of the slightly projecting grid lines previously plotted on the mount. The grid lines are numbered, and all lettering, such as names of towns, rivers, etc., and a border and marginal data (par. 48*b*) are added to the mosaic. (See fig. 188.)

h. Reproduction of finished mosaic.—When the mosaic has been titled and finished it is ready to be copied. After being checked it is sent with the necessary instructions to the reproduction unit. Copies may be photographic prints, half-tone lithographs, or full-tone lithographic prints. The first two, because of consistently better clarity and sharpness of detail, are usually preferred.

Section XXIII

REDUCTIONS AND ENLARGEMENTS

102. General.—*a.* Because of the increased use of aerial photographs in topographic mapping, drafting room operations for reducing or enlarging the data from the photographs have correspondingly increased, as photographs and finished maps are seldom of the same scale. Enlargements are very seldom made, as errors that may be acceptable on smaller maps are enlarged proportionately and the enlargement then is often unsatisfactory.

b. Reduction (or enlargement) is done at some time during the process of converting photographic data into map data. Conditions such as available equipment, time, etc., determine to a great extent just when and with what method the reduction or enlargement is to be accomplished.

c. The photographic method can be used in any case, no matter whether photographs or drawings are involved, and is the quickest and most accurate method. Either the pantograph or the grid method can be used to transform drawings (maps, etc.) from one scale to another. Because of the time necessary to adjust the pantograph it is usually more economical to use the grid method if the area to be transformed is small.

103. Grid method.—Reductions or enlargements by the grid method are made as described in paragraph 93*b*.

104. Pantograph.—Reductions or enlargements by pantograph are often resorted to. For a description, etc., of the pantograph see paragraph 9*o* and 16.

105. Photographic methods.—*a.* When a photograph or drawing is to be reduced or enlarged by photography, specific instructions should accompany the request for the work. Since scale and correct form of the reduction or enlargement are of greatest importance in mapping, it is always best to include in the instructions the exact size of the finished product (width, height, and, if possible, length of diagonals) and the type of paper desired.

b. If a map has to be made to a larger scale than the photographs available, it is best to make enlargements from the photographic negatives first, then construct the map from these enlargements.

SECTION XXIV

OUTLINE OF COMPLETE INSTRUCTION COURSE

106. General.—*a.* A typical training course, details of which are given in the different sections of this manual, includes 33 exercises. The first 17 of these are to be considered basic instructions and the remainder advanced instructions.

b. The training course as here outlined will assist instructors in planning exercises for a course based on local conditions which will naturally vary and influence the character and type of the instructional material.

c. The time allotted to finish each exercise is based on the average from a class of 25 students over a period of 3 years and should be sufficient for those showing aptitude and a willingness to learn.

107. Basic instructions (exercises Nos. 1 to 17, incl.).

Exercise No.	Subject	Par. No.	Fig. No.	Hours for pencil	Hours for ink	Total hours
1	Freehand lettering—slanted capitals	20*e*	67	10	6	16
2	Freehand lettering—slanted lower case	20*f*	68	10	6	16
3	Freehand lettering—vertical capitals	20*g*	69	8	5	13
4	Freehand lettering—vertical lower case	20*h*	70	8	6	14
5	Map lettering—Gothic and roman	21*c*	76	13	8	21
6	Conventional signs—works of man	22*b*	82	13	8	21
7	Conventional signs—natural features	22*c*	83	13	8	21
8	Military symbols	22*d*	84	8	5	13
9	Miscellaneous drawings—grid lines and scale	23*b*	85	12	------	12
10	Miscellaneous drawings—topographic diagrams	23*c*	86	12	6	18
11	Contour and road pen exercise	24*b*	87	------	8	8
12	Map tracing	24*c*	88	------	16	16
13	Map drawing (colored)	24*d*	89	14	7	21
14	Contour interpolation problem	36*f*	109	7	------	7
15	Ground form line problem	36*h*	110	4	------	4
16	Planimetric detail from photograph	37*e*	111	7	------	7
17	Contours and planimetry from photographs	38*h*	112	14	------	14
	Total (basic course)	------	------	------	------	242

a. Exercises Nos. 3, 4, 5, 7, and 8 may be omitted if time for training instructions must be curtailed, reducing the total for a minimum basic course to 169 hours, approximately 24 days.

b. Men who are trained for topographers whose duties would largely be in connection with field work should be required to complete exercises Nos. 1, 2, 6, 7, 11, 14, 15, 16, and 17 requiring a total of 114 hours, approximately 16 days for basic instructions.

c. Many another combination of the exercises will suggest itself to those responsible for instructions in these subjects.

108. Advanced instructions (exercises Nos. 18 to 33, incl.).

Exercise No.	Subject	Par. No.	Fig. No.	Hours for pencil	Hours for ink	Total hours
18	Profile and grade line	54*d*	114	2	2	4
19	Cross section from topographical map	55*b*	115	4	------	4
20	Cross section for road	55*c*	117	4	------	4
21	Polyconic projection	59*b*	126	7	4	11
22	Grid coordinates	61*b*	130	4	3	7
23	Plotting traverse by polar coordinates	67*c*	135	2	1	3
24	Plotting traverse by rectangular coordinates	67*e*	136	2	1	3
25	Construction of ground control sheet	68*d*	137	7	3	10
26	Preparation of flight diagram	69*b*	139	2	2	4
27	Selecting points and marking photographs	75*d*	148	------	14	14
28	Plotting photographic control by radial line method	78*r*	157	11	3	14
29	Planimetric detail tracing from photographs	87*b*	170	------	14	14
30	Contours with stereo-comparagraph	88*j*	175	63	------	63
31	Compilation of stereo-comparagraph sketches	88*k*	178	14	7	21
32	Compilation of a map	94*i*	180	35	14	49
33	Radial line method of restitution	97*g*	184	1	1	2
	Total (advanced course)	------	------	------	------	227

The time consumed to give the advanced course together with the complete basic course would be 469 hours or approximately 67 days. This should be sufficient time to develop the average man with a little aptitude for this type of work, into a draftsman of more than average ability who, with additional experience, should be able to complete any task that may confront the military photogrammetrist.

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[A. G. 062.11 (5–10–40).]

BY ORDER OF THE SECRETARY OF WAR:

G. C. MARSHALL,
Chief of Staff.

OFFICIAL:
E. S. ADAMS,
Major General,
The Adjutant General.

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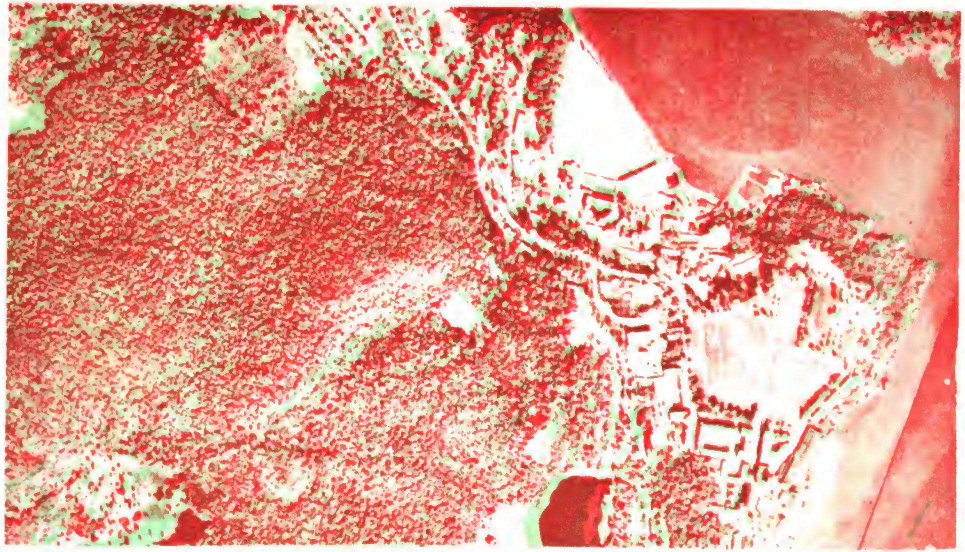
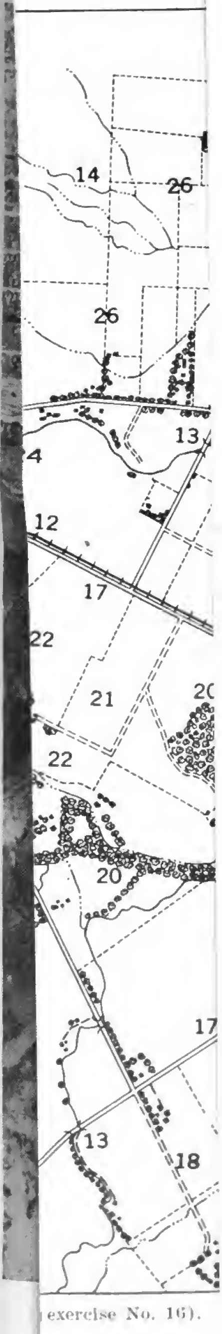


FIGURE 107①.—Anaglyph.



exercise No. 16).

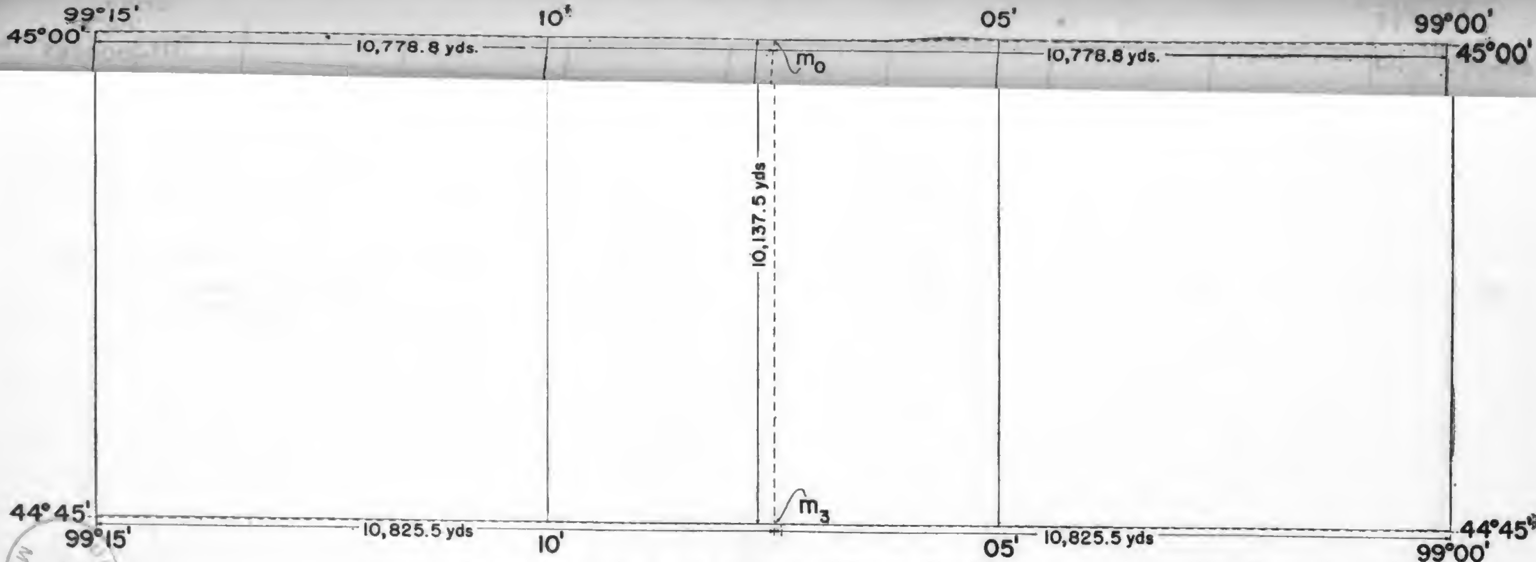


FIGURE 126.—Constructing polyconic projection (exercise No. 21).

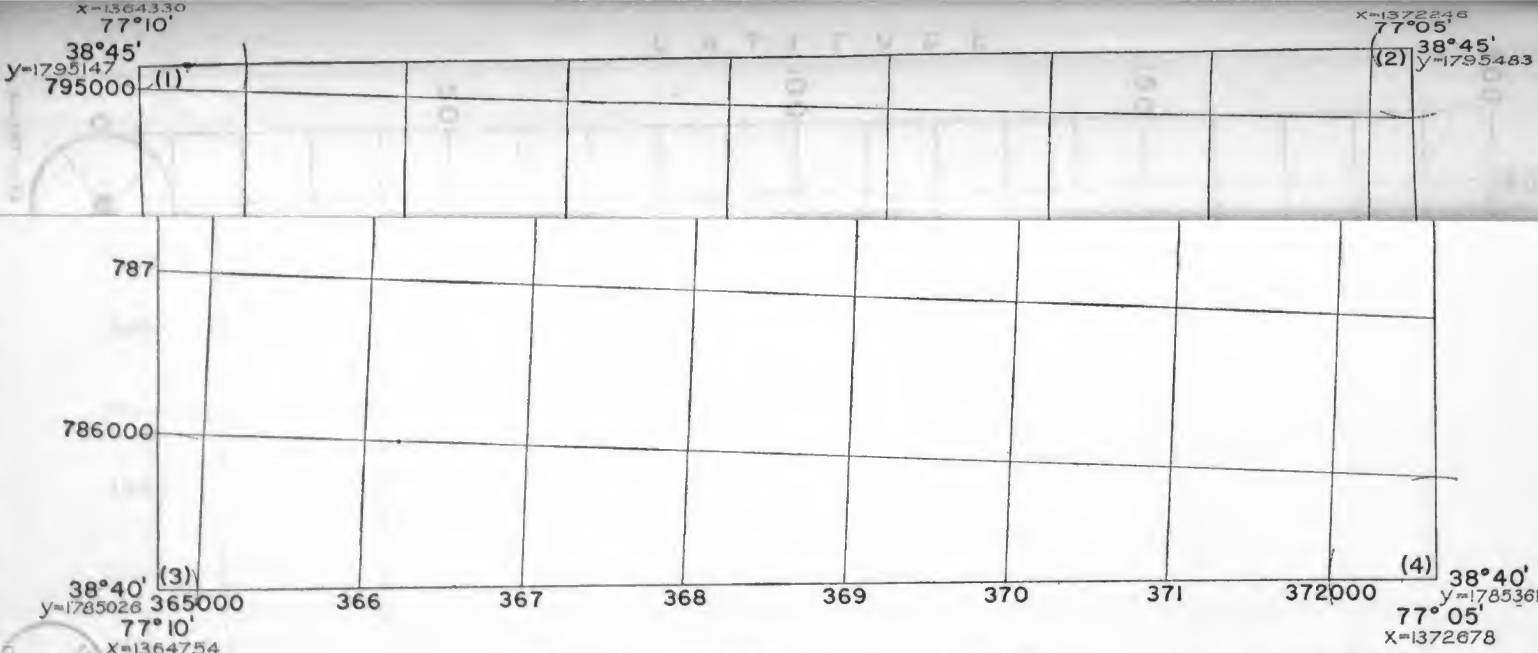
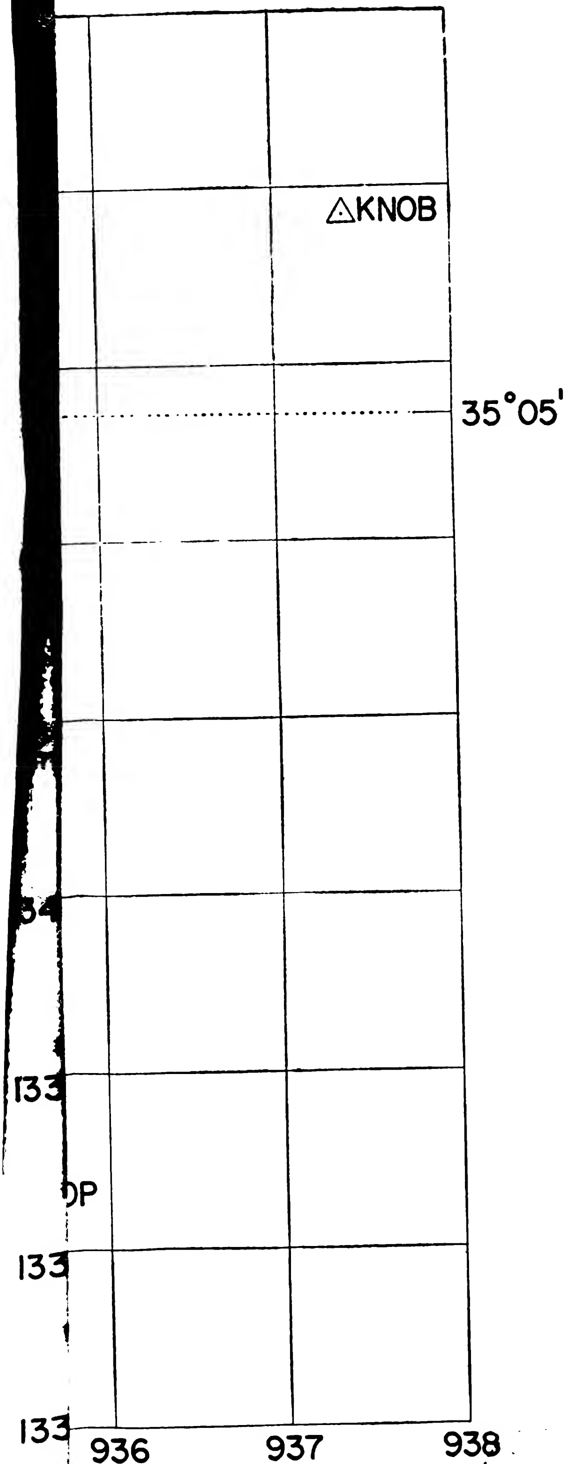


FIGURE 130.—Superimposing grid coordinates (exercise No. 22).

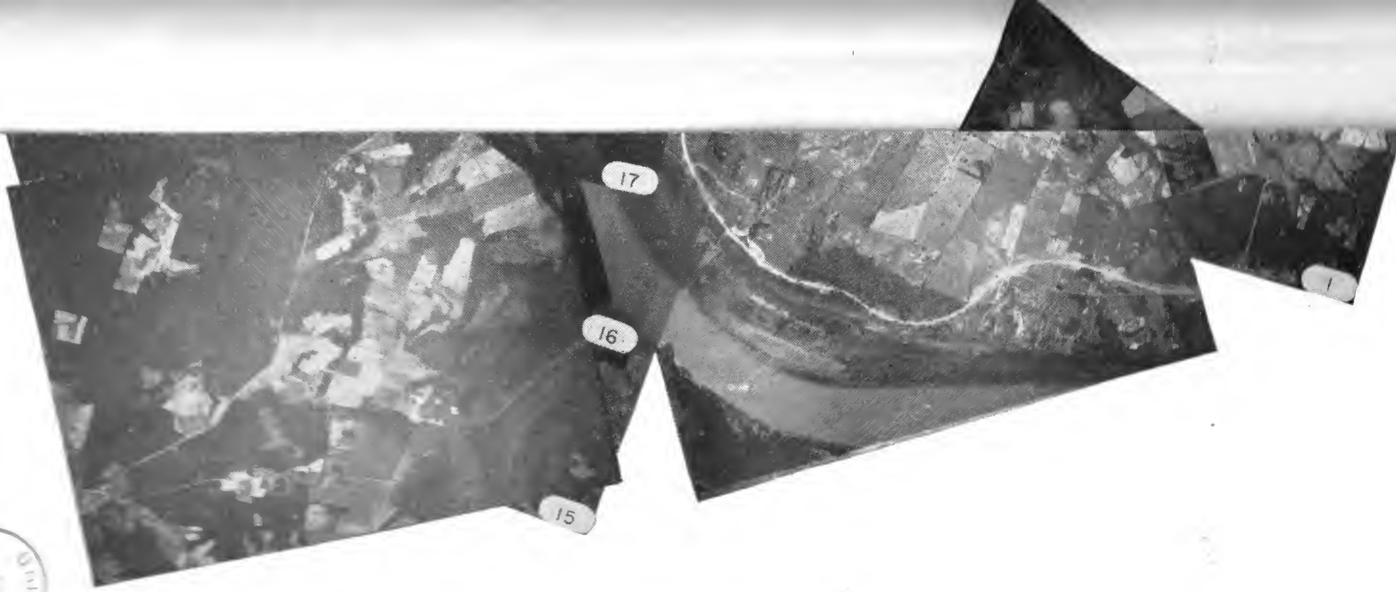
455462°—42 (Face p. 156)


100
14
99
98


98
15
CAMP



—42 (Face p. 166 No. 1)



455482°—42 (Face p. 169)

FIGURE 141.—Index mosaic.

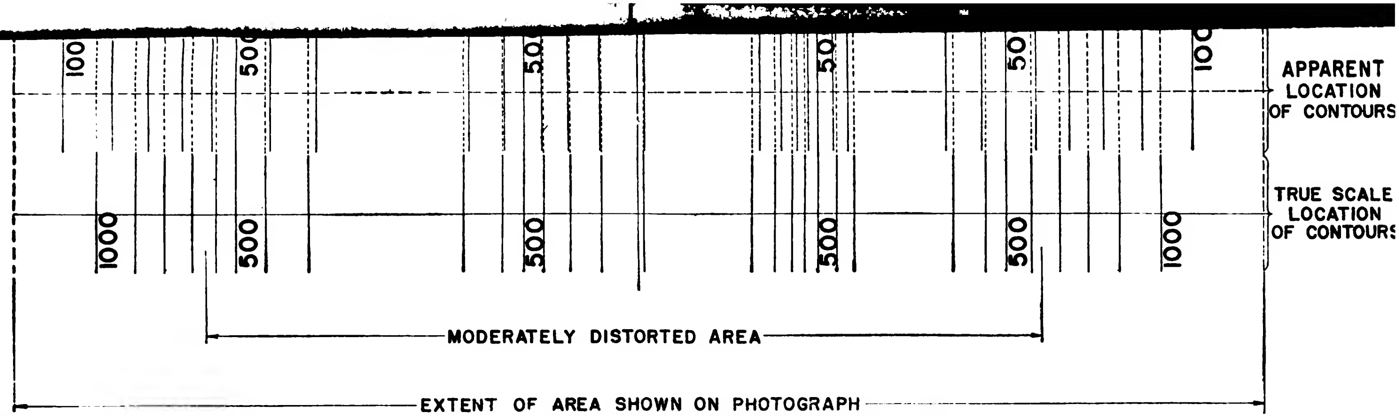
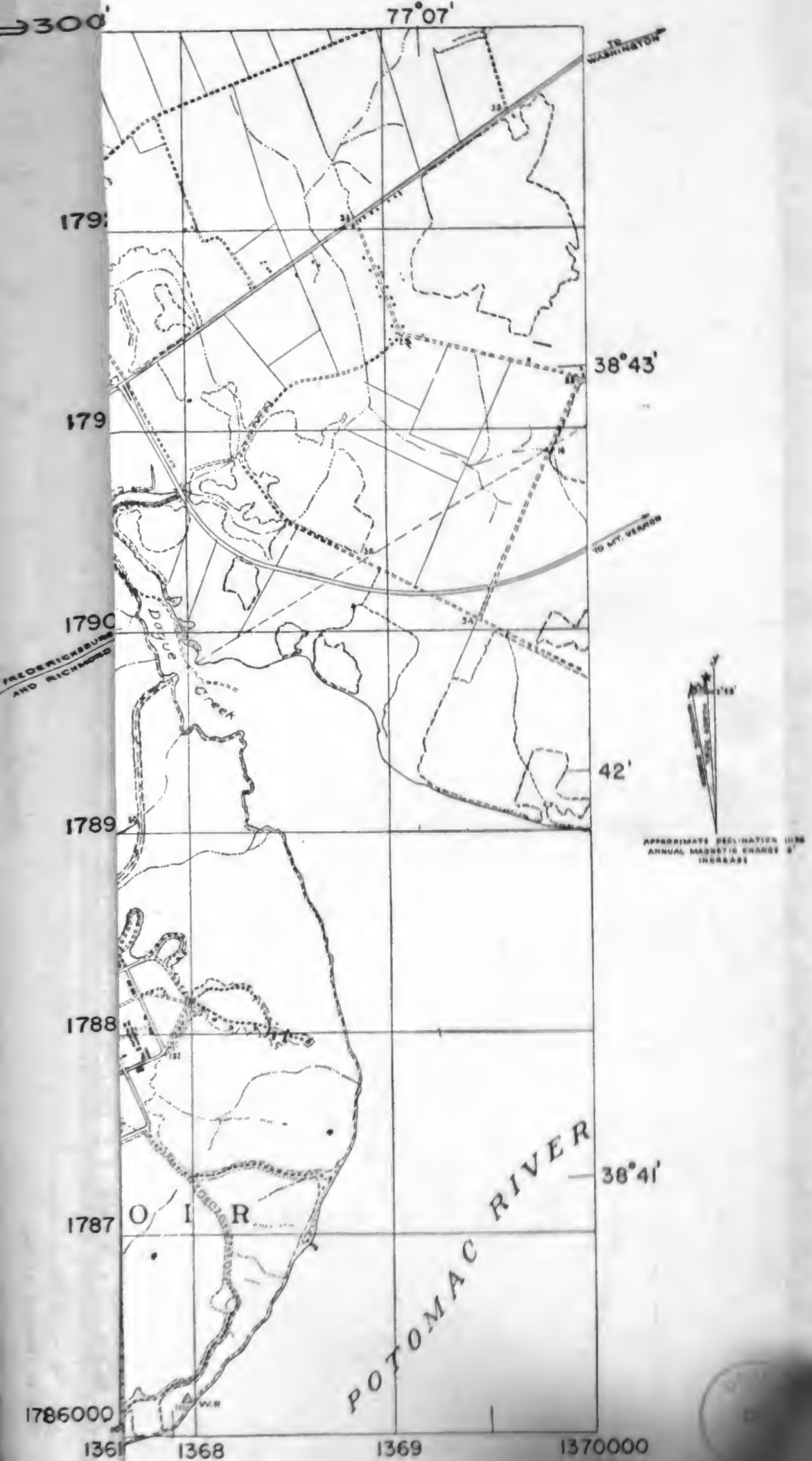


FIGURE 144.—Horizontal scale distortion on single vertical photograph due to ground relief.

455462°—42 (Face p. 172)



77°07'
TO WASHINGTON
38°43'
TO MT. VERNON
Dogue Creek
FREDERICKSBURG AND RICHMOND
1790
42'
1789
1788
38°41'
POTOMAC RIVER
O I R
1787
1786000
1368
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